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Mysteries of Our World

Also by Peter Briggs

Rivers in the Sea

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Science Ship

Men in the Sea

Water: The Vital Essence

Mysteries of Our World

Unanswered Questions About the Continents, the Seas, the Atmosphere, the Origins of Life

by PETER BRIGGS

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MYSTERIES OF OUR WORLD

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"What is scientific thought but common sense well regulated?"

—Thomas Henry Huxley

"Those miracles of nature are now attributed to some abstract formula, as they will be to some fresh one, and to a dozen more, before the century is out, because, the more accurately and deeply they are investigated, the more inexplicable they will be found."

Charles Kingsley,
A Christmas In the West Indies, 1871

"When should you plant the marigolds? One of these days oceanography will be able to tell you."

—Anonymous

"Our earth is very old, an old warrior that has lived through many battles. Nevertheless, the face of it is still changing, and science sees no certain limit for its stately evolution.... And the secret of it all—the secret of the earthquake, the secret of the "temple of fire," the secret of the ocean basin—is in the heart of the earth, forever invisible to human eyes."

—R. A. Daly,
Our Mobile Earth, 1926

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In Acknowledgment

The questions and facts about science discussed in this book are the results of a tremendous amount of work done by a great many individuals. About the best a writer on such a subject as this can do is give thanks in a general way that the rational community of science exists.

I can, however, personally thank a number of people who generously gave me their time, advice, and encouragement; Dr. Langley Wood, now of the University of New Hampshire; Dr. Neal Opdyke of the Lamont-Doherty Geological Observatory; Dr. Thomas S. Austin of the National Oceanographic Data Center; Dr. Harris Stewart, Jr., and Dr. Robert Dietz, both of ESSA's Atlantic Oceanographic Laboratories in Miami; Dr. William Hargis, Jr., of the Virginia Institute of Marine Science; Roland Paine, Jr., of the National Science Foundation; Dr. F. C. Fuglister of the Woods Hole Oceanographic Institution; Miss Faith Turnbull of the Institute of Marine Sciences (University of Miami); Dr. Peter Barrett of the Institute of Polar Studies at Ohio State; and Dr. John A. Knauss of the University of Rhode Island.

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Needless to say, whatever errors the book may contain, they were committed entirely by the author.

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Mysteries of Our World

I.

What We Don't Know, That's What Matters

AN inspired professor at Virginia's Institute of Marine Science conducted a class for graduate students in what no one knows about his subject. He was Dr. Langley Wood, Senior Marine Scientist of the Gloucester Point campus across the river from the site of the Battle of Yorktown. His course concerned marine oceanography. After inviting colleagues from all over the country to give their advice, he prepared a 20-page list of problems in ocean biology that need to be solved. This list covers such general questions as "What factors regulate the populations of ocean species?" and such curious ones as "How do fish communicate by sound?" and "What function is there for the cold light produced by one-third of all marine animals?" Writing about Dr. Wood's project, a scientist at another university said, "It will do the students good to realize that there are so many gaps in our knowledge."

It might do us all good, graduate student or just newspaper reader, to understand that the scientists have not finished changing our world or our concept of it. In fact, they have hardly begun. What more do the researchers want to know; what is left for them to find out? The men on the knowledge frontier say frankly that they do not

know. They may, like Dr. Wood, prepare a "Don't Know" course, but this only covers their present state of ignorance. Like explorers following the course of an unknown, winding river, each time they round a bend and believe they have reached a goal, another bend appears before them, and what is beyond remains a mystery until they travel it.

Science has been fashionable for the layman ever since atomic bombs exploded over Japan and on newspaper front pages in 1945. Beyond the awe and terror it inspired, the destruction at Hiroshima came as such a shock because so very few people in the world even knew such a thing was possible. Mad scientists were no longer people who only existed to be laughed at in horror films. Science fiction was not fiction at all. Researchers who could outdream the science writers actually existed, and, even more, they had the knowledge to put their dreams into reality. Now we have trips to the moon, communications satellites, heart transplants, man-made elements, laser beams, transistors, computers, and submersibles that can explore every inch of the sea bottom. And this list covers only a fraction of the astonishing developments of which the public has become aware in just the last twenty years.

Most of these radical new things we must become used to are really triumphs in technology, not pure science. Each of them, however, was founded on basic research, on the discovery of laws of nature for which, at first, no practical use could be seen. The average person can get the general concept of most of the new things constantly appearing, at least what they are supposed to do, if not actually how they work. Only the specialists usually know the scientific principles that underlie such matters. This seems unfortunate, not only because the scientists tend to draw farther and farther away from our commonsense world, not only because developments from here on in will be even less

understandable scientifically, but because the average person does not take any part in the exciting intellectual adventures that are going on in the world of pure research. If only more of us at an early age had been given "Don't Know" courses we might have been stimulated to more serious study, and the world of science might not be in such danger of becoming an alien nation in our midst.

Of all the school courses apparently designed to keep interest at a minimum, those devoted to science, at least until recently, were the worst. If they knew that any exciting frontiers existed, high-school teachers in particular kept the secret to themselves. Science studies also suffered from the fact that students who were serious about it never became social leaders. Who can tell how many people, ones whose teachers told them they were "bright," avoided the most stimulating intellectual exploits of their time because they had no idea at all what was going on? (Scientists bear some responsibility for all this, too. Aware that everyone outside their sphere considered them drab or strange, they barricaded themselves in laboratories, invented languages only a few of their fellows could understand, and assumed a defensive attitude that is still often hard to break down.)

Now, however, the scientists and their attendant engineers are getting a sort of revenge. No one, least of all an illiterate manual laborer, can manage to escape the effects of all the scientific events that have poured forth in the past thirty years. The illiterate, the untrained who cannot grasp the ever more complicated tools used in industry, have no role in the new labor market created by developments in electronics, atomic energy, chemistry, aeronautics, space technology, automation, or the many even newer industries that have hardly yet found a place in an educated vocabulary.

For the moderately educated, however, the separation

between science and man has been narrowing recently. Sometimes it may be good business to know what the future will bring. Often a piqued ego will demand to understand what is going on and why few ideas and no machines remain up to date for more than a few years. (This obsolescence, of course, applies to most social problems, too, but one root cause of social dislocation is the changing science and technology, and the disruptions of the economy they continuously generate.) Whatever the reason, many people not directly involved are consciously broadening their scientific background. Scientists aware of the extent to which they are revolutionizing the world now descend from their towers to try and explain what they are up to.

A delightful discovery about scientists is that they are hardly ever madmen. They are full of good will. What they really want are answers for all the things they do not know. They happily acknowledge that there are many more questions than there are solutions. If there were nothing else to be learned, as one of them said recently, "We'd all be out of our jobs." In a letter, Dean John A. Knauss of Rhode Island University wrote, "As has often been said, 'A problem not yet solved is interesting. Once you know the solution, the problem is trivial.' Thus, the thing you get all scientists to talk about is not what is known but what it is they are trying to find out."

What the scientists are trying to find out now is what they will discover next. The best science news stories always give an idea of the final research goal. For the layman trying to keep pace, the best chance is to know what the questions are at the moment. The questions are the signals for the breakthroughs. In reading, talking, or thinking about all this, the big question is "What remains to be learned?" The answer to any important scien-

tific question will sooner or later have an effect on your life.

This book is one of many that try to bridge the unfortunate gap between men of special learning and people who would like to understand what they do. It differs from most other such books in that it aims to throw some light on the far edges of even the specialists' understanding. It does not stress those scientific matters that are settled, although enough background has to be given so that the questions themselves make sense. There is some bias in the book toward things dealing with the oceans because, in terms of understanding our world, the oceans are the areas where the greatest activity is going on today. It is hoped that none of the questions scientists are now asking will seem academic.

Once upon a time, basic research used to be called "academic." It could be dismissed because it had no practical goals. Now, however, no academic questions actually exist. Whatever we learn about the earth is important to us. If men understand the processes of geology, biology, or the facts about the weather and the sea, for instance, the knowledge can be used to control events for man's benefit. It may also be useful to understand what goes on to insure the survival of the human race. One thinks immediately of the effects of pollution, radioactive and otherwise, on our incredibly complex biological world.

In the past, a few special people were called "universal men." Thomas Jefferson was one of these. He knew almost everything that an educated man in his day could know. Benjamin Franklin was another such American, and they had friends, their counterparts in Europe, who were equally learned. They understood agriculture, astronomy,

architecture, physics, mathematics, geography—everything that had been learned at that stage in history.

Jefferson and Franklin were also practical men, both as interested in invention as in "natural laws." (The modern division between basic research and technology would probably have seemed unreal to them.) But the broad range of interests of these two founding fathers did not start an intellectual tradition in the United States. They *ended* a tradition, a line that began with Aristotle and included Leonardo da Vinci. By the time Jefferson died (1826), no one man could hope to know all natural science.

The intellectual revolution had begun. In the nineteenth century it produced such marvels as the steamboat, the telegraph, the railroad, the submarine, photography, and the gasoline engine. It also produced wonders such as anesthesia, the germ theory of disease, vaccination against smallpox, and ideas disturbing to religion, such as the theory of evolution, including dinosaurs, and the age geologists gave to the earth. Each new invention and discovery, of course, stimulated others.

The store of information now available about our world has continued to swell with ever-increasing speed, particularly since World War II. In the United States, federal aid to higher education and generous support of basic research has caused scientific barriers to be broken even before it was fully realized they existed.

New sciences continue to be born (symbolic of ever-increasing specialization) with names such as psychobiology, paleomagnetism, radio astronomy, weather modification, and geochemistry. Scientific libraries contain hundreds of thousands of different books. At the New York Public Library the count is over 900,000. Countless

research papers are published in a bewildering number of scholarly journals.

There seems no let-up due soon. Computers seek out, in all this mass of print, the publications a researcher may need for his particular problem. The scientist needs help merely to assemble the right pieces of paper. Few men today are complete masters of even their own specialty.

With all this frantic activity in research, not only in the United States but in Western Europe, Russia, and Japan, it would seem as if the scientific millennium will someday arrive. The frontiers will be conquered and we will completely understand our world.

All this great scientific advance, however, has revealed an awesome dilemma. With practically every new bit of knowledge, it turns out now that new questions appear, waiting to be answered. *Webster's Collegiate Dictionary,* copyright in 1936, said that an atom is "the smallest part of an element that can exist." Now a whole series of atomic particles have been found. What are they and what are the laws of their behavior? Here is how the dilemma and challenge work in another field.

Geography was an apparently static science with just about all the features known, until someone realized a small oversight had been made and that no one had any maps of the bottom of the sea. Now a whole new realm of the earth is being discovered, full of vast mountain ranges, deep trenches, deep rifts and great fractures like wounds on the ocean floor, buried volcanoes, and evidence of massive earth movements only dimly understood. Explaining the origin of all these recently discovered features is the province of geophysics, and today this science is one of the liveliest of all. The lure of achievement, men's thoughts that they personally may provide the answer to

all the new mysteries about the earth, these incentives have caused men from many allied fields to look at geophysical problems. Dr. J. B. Heirtzler of Columbia University, one of the most prominent researchers in the area, in 1968 described the activity in just one area of the subject, magnetism. "In only three years a great deal has been learned, so many different workers have made significant contributions that it is impossible to name them all in a brief review or even always to know who was the first to make a new observation or propose a new model." (What a difference from the leisurely days of Jefferson and his scientific friends.)

Here is a partial picture of what is going on, most of it completely unknown to the general public.

A man sits high above the Hudson River in Palisades, New York, plotting the course of the South Pole as it wandered across Gondwanaland about 250 million years ago. He must consider facts from many sources.

He must reckon with the findings of an Englishman who is comparing the ages and composition of prehistoric red sandstone found in the British Isles with comparable red sandstone exposed on the cliffs of the Grand Canyon in Arizona.

The man in New York must also think about the theories of a colleague who found tektites, possibly meteoric glass, in sediment cores taken from the bottom of the sea over a large area of the Indian Ocean.

While thinking about a moving South Pole, he is also theorizing on such strange phenomena as old coral reefs in the Arctic Ocean, evidence of tropical seas in what is now northern Canada, coal deposits and the recently discovered fossil of a fresh-water amphibian in the frozen mountains of the Antarctic, and evidence that great sheets

of ice once covered parts of Africa, India, Brazil, and Australia. These things are odd, for instance, because coral requires at least a subtropical climate for life, and coal is formed only in areas with warm, wet climates and dense forests or swamps.

He wonders, too, about the disappearance at various times in the last five million years of various species of a plankton called radiolaria. Observations of sediment cores taken from the bottom of the sea around the Antarctic show that they vanished suddenly. Could the extinction of these radiolaria be related in some way to the extinction of the once-great dinosaur family? There is at least one good reason for thinking the disappearances have something in common.

The man in Palisades, New York, one of many trying to bring order out of the infinity of known facts, is Dr. Neil Opdyke. Of Dutch descent, from New Jersey, he works at the Lamont-Doherty Geological Observatory, part of Columbia University. His special study for some years has been paleomagnetism. "Paleo" is from the Greek, meaning "in the past, old or ancient." Magnetism is a word most people feel free to use though, in fact, no one understands it. It is generally believed that magnetism is generated as the molten iron of the earth's outer core spins in response to the earth's rotation. In any case, magnetism is expressed on the surface of the planet. Any substance containing iron, including rock, is magnetized. As in a compass, the magnetic field of the substance points toward the North Magnetic Pole.

Recently, however, it has been discovered that many magnetic bits of the earth do not point north, but rather south. The South Magnetic Pole attracts them. Somehow, a reversal of 180 degrees has occurred. Through correla-

tion with proven methods of geological comparison between various rocks, and by checking the figures derived from radioactive dating, it has been shown that the world has had 171 magnetic reversals in the last 76 million years.

What difference does this make? Why should anyone but a paleomagnetist care? First, because the fact of reversals gives a valuable tool for reconstructing the history of the seas and the continents. Last, because an explanation of the fact may predict how much longer the human race can remain on earth. In between, it may explain why the Antarctic contains coal.

Rocks have no magnetism in their initial stage, as molten lava, but they acquire it as they cool. Their magnetic fields are oriented to the magnetic pole as it existed during the time of cooling. Now that the dates of magnetic reversals have been learned, it is possible to tell the age of a rock from its orientation.

It is not believed that the geographical poles have changed very much during the time the earth has existed. Thus, the North and South Poles must always have been very cold. Yet there are evidences of temperate if not tropical conditions, for instance, at some period during the history of the Antarctic. Thus, if the poles have been constant, the Antarctic must have been somewhere else. (The evidences of great changes in the climate exist not only in the Antarctic but on all continents.)

Moving the Antarctic is one of the features of a now very popular theory known as "continental drift." In the very broadest terms the theory says that the earth originally had only one continental mass, called Pangaea, or at best two masses. Gondwanaland, south of the equator, consisted of Africa, India, Australia, the Antarctic, and South America. Laurasia, north of the equator, included Europe, Asia, and North America. Biological and geo-

logical similarities between these various lands, as well as the obvious fit between Africa and South America, all support the idea of continental drift.

How could the continents have broken apart, moved such vast distances, and what has this to do with paleomagnetism? The answer, first proposed in 1956, may lie in the rift that runs down the center of the mid-Atlantic and the Indian Ocean through a submerged mountain range. It includes the new theory of "sea-floor spreading." The general idea, proved by observations, is that the earth is very seismically active at the rift. It has many earthquakes. The heat flow from the earth's interior at the rift is much greater than it is on other parts of the ocean floor. The theory says that hot lava comes to the surface at the rift and pushes older lavas away to one side or the other. These older lavas have the magnetic polarity they acquired at the time they cooled. Surveys of these remains of past intrusions show a pattern of magnetic reversals, always working out from the center, that can be dated back millions of years. As they are forced away from the rift, these masses of material in turn force the continents (which they have already broken apart) away from each other. The ancient magnetism of the rocks, then, shows how there can be coal in the Antarctic.

This magnetic detection work has had a great impact on scientific theory. As always, the discovery raises at least as many questions as it answers. How, for instance, could the reversals have come about? One recent idea is that nearby explosions of enormous cosmic bodies entering our orbit have been the cause. Remains of such explosions, tektites, have been dated as 700,000 and one million years old, the times of the last two reversals. Another current speculation is that the magnetic poles

change sometimes when earthquakes on a major scale cause slight changes in the earth's orbit. Quite simply, no one knows, and so a great new field for research has been opened up.

Scientists believe that a complete switch of the earth's magnetic field may take about 5,000 years to complete. During at least part of this time, the earth loses much of its magnetic shield, the Van Allen belt that extends far out into space. Without this magnetic shield, which prevents most of the cosmic rays of outer space from striking the earth, all life here would be exposed to their very lethal impact. If these radioactive rays did not kill, they could at least cause many harmful mutations. As mentioned, Dr. Opdyke of Lamont-Doherty found a very striking relation in time between the disappearance of some species of radiolaria and the reversals of the magnetic field. At least one author has criticized the idea, insisting that the fact of the two events being simultaneous was a mere coincidence, but Opdyke believes he now has so much evidence that coincidence has been ruled out.

If radiolaria can become extinct because of cosmic rays, why not other species? Why not dinosaurs, for instance? Or man? There seems to be evidence that the force of our magnetic field is declining at the moment. If this is true, it might reach the zero point in a few hundred or a few thousand years.

What this would do to the human race is a question of more than academic interest. In fact, it might be quite worthwhile to know. If it should be understood why the poles reverse themselves, then, perhaps (and this requires some imagination) someone will devise the big bang that can prevent the reversal from happening. After all, the Van Allen belt has already been joggled once during a

high-level thermonuclear explosion. What will the next generation think of? The fact that no one knows makes the future, in spite of many gloomy predictions, a woolly but wonderful prospect. Science seems worth keeping up with.

II.

Why Does the Earth Exist?

IT does not seem likely that anyone will ever celebrate the day the earth was born. In spite of the many myths about creation, our world certainly did not spring forth between a single morning and night to fill a void in the sky. The development probably took something more on the order of millions of years. Of all the countless questions that may be asked about it, the most elusive one will certainly be how or why it ever developed.

Nevertheless, astronomers actively seek a solution to the problem. They have made unbelievably complex reckonings about the stars, discovered distances beyond comprehension, predicted the movements of celestial bodies with split-second precision, and found mysterious new features such as radio stars, quasars, and pulsars. Still, they cannot tell us with any certainty at all the reason, or reasons, for our having a globe to walk upon.

Astronomers and their cousins, the mathematicians, have certainly tried to produce a hypothesis that will survive criticism. The German philosopher, Immanuel Kant, and later the French mathematician, Pierre Laplace, separately produced an explanation that survived as gospel for sixty years. It is often called the Nebular Hypothesis.

It said that the solar system was once a huge gaseous cloud that condensed into the planets and sun due to both gravitation and heat loss. An Englishman, James Clerk Maxwell, and later an American geologist, Thomas E. Chamberlin, demolished the Kant-Laplace theory by showing that it contained several contradictions and also defied the laws of physics. More recent research showed that the sun differs from the planets in kind and could not have been produced from the same cloud. In addition there are heavy elements in the planets, such as uranium, that could only have come into existence at temperatures far greater than any existing on the sun.

Chamberlin and Forest Moulton of the United States, working together, and Sir James Jeans of England, working separately, all devised a theory of the origin of the solar system that requires a near collision of our sun with a star of almost similar proportions. As the two suns approached, the attraction of their two gravities drew masses of material away from each. These became the planets. The passing sun moved away, taking half the planets with it. The earth and the other planets remained to orbit around our sun. The planets were formed, according to the Chamberlin-Moulton theory, not as immediate, molten objects, but as particles of the sun that gradually coalesced together by force of gravity. Chamberlin's and Moulton's idea was demolished on a number of grounds. One was that the orbits of planets formed in this manner would be a very long ellipse while, in fact, the planets' motions are nearly circular. Jeans's theory did not survive the fact that the mathematical probability of such a collision is so remote that the chance of two such stars meeting is simply absurd.

More recent theorists have modified some of the objections to the collision theory, but have by no means

satisfied their critics. The other general idea now is that the planets were gradually collected and condensed from matter flying around the sun. This might have come from a nearby sun that exploded and whose material became attracted to the sun's orbit. The pros and cons become increasingly technical, understandable mainly to students of astronomy. Basically, no one knows why we have our earth. How long we have had it is another matter.

Poor Bishop Ussher! So many writers have laughed at him, yet he must have worked very hard while determining the age of the earth. Consider the amount of labor necessary to announce the date with Ussher's precision. The earth began at 9 A.M. on October 29, 4004 B.C. How did he arrive at this remarkable figure? He used the best evidence he knew, the Old Testament of the Bible. Perhaps he had heard something of the new scientific method and considered that he was being very scientific. He certainly felt he had chosen the best source. After all, the Book of Genesis gives the exact age of all eleven patriarchs. From Adam's birth to Noah's death, their lives spanned 1,634 years. With such an assist, a dedicated man can fill in the rest. The date of 4004 B.C. is given in a Bible published by Oxford University Press, last copyright 1943. Certain ideas die hard.

Faith in the accuracy of the Bible and the firm hand of religious tradition made scientific study of questions such as the age of the earth very difficult, even dangerous. Galileo was nearly burned at the stake in 1623 for writing that the earth moved around the sun. Nevertheless, geology, a word coined by a teacher in England in 1735, was born and began its slow growth. No absolute dates were possible. Comparative times for rocks and sediment fossils were worked out, primarily in England at first. Names were given for eras, such as Cenozoic, Mesozoic,

and Paleozoic (the last ran from 500 million to 230 million years ago, taking a number of millions one way or another). Other names were agreed upon for periods, the next smaller divisions. The Cretaceous, age of the dinosaurs, is perhaps the most familiar of these. The smallest divisions finally used were epochs. The division most important to man is the most recent, the Pleistocene, the last one, during which perhaps a million years elapsed. This is the epoch during which man-like creatures emerged and also the time of the famous four Ice Ages. (Dr. Opdyke says, however, that there were eight in the last 700,000 years.)

Before all the times that can be dated, at least in relation to one another, lies a dim era known as the Pre-Cambrian. It ended, more or less, about 500 million years ago; it began when the earth began. New findings have recently caused the presumed length of the Pre-Cambrian to increase. Most respectable books during the 1950s have it beginning about two billion years ago. Then a new tool began to be employed for dating rocks. It is one of the peaceful uses of radioactivity.

Dr. Willard Libby of the University of Chicago is given the credit for first seeing in 1945 that ancient organic material might be dated by measuring the half-life of the radioactive carbon that it contained. All living material carries the same proportion of radioactive carbon when it dies, and at that moment, the radioactive carbon begins to disintegrate. Unfortunately, not enough of this carbon remains after 30,000 years for any more half-life to be detected. Libby's discovery, therefore, is of no use in dating rocks.

Other radioactive elements can be used, however. The first tests were on uranium, which disintegrates into lead, and then it was discovered that radioactive potassium,

which decays into argon, was an even better element to use to find the age of a specimen of rock. Dated by classical geologic methods, the oldest rocks so far found on earth have been in Rhodesia. Both the classical method and potassium-argon dating show these rocks to be 2.7 billion years old. Interpreting backward to the time when this rock must have been formed (based on the degree of its potassium decomposition), this rock is about 4.5 billion years old. At the moment, this seems to be the age of our earth. The age of the universe remains a matter of conjecture.

Our moon, the gibbus, harvest, crescent, inconstant moon, pulls away from the earth at the rate of 48 inches every year. That our one natural satellite becomes annually four feet farther away does not seem much cause for alarm. This is not much added to a total distance of 238,857 miles. To our grandchildren, the moon will look exactly the same as it does to us. In the history of our planet, however, this gradual separation has enormous significance. For instance, since it is moving away, the moon must have once been a great deal closer to the earth.

The most obvious importance of the moon to the earth is the fact that its gravity creates our ocean tides. Less well known is the fact that the moon creates tides in the land itself. Though not visible to us, since our bodies are part of the motion, the solid surface of the earth, cities, mountains, and all moves up and down every day in response to the pull of the moon. The action is only a few inches either way but is perfectly real, and it may be one of the major causes for the changes that go on constantly in this planet.

As the moon recedes from the earth, it has less and less effect on our seas and land. Its power is still great enough, however, so that the friction within the water itself, the

friction of the water on the sea bottom, and the collision of the tides against the shores, all use up energy and slow down the earth's rotation. Each day is 200 billionths of a second longer than the last one. Fossil studies of corals, animals which add a growth ring every day, show that a year on earth had 428 days at the beginning of the Cambrian period. When the middle of the Devonian period came along, about 300 million years ago, the days had lengthened until a year lasted only 400 days. It is the earth's slowly decreasing rate of rotation that is causing us to lose our moon. According to the physical laws discovered by Sir Isaac Newton, if one body slows down, the body opposed to it must speed up and move away.

In 1871, George Darwin of the famous English family of scientists used this receding motion to explain the existence of the moon itself. He claimed, mathematically, that the moon must have just about been touching the earth 4.5 billion years ago. Then the earth-day would have only been four hours long, and the duration of a lunar month just four hours. Just before this, at the time of creation, when the earth was still molten, when there was no lunar tide, the sun would have caused one on earth every two hours. At a moment when the oscillations were just right, a great fragment of the earth could have been torn off to begin its journey in space. The area from which the moon was torn is now the basin of the Pacific Ocean. This was Darwin's controversial theory. Naturally it has been objected to.

A major opposing theory is that the moon was a small object in space that gradually accumulated debris from some cosmic explosion, eventually reaching its present size. The numerous craters on its surface are thus not volcanic but entirely the results of meteors.

Current space explorations may help provide an answer.

On October 1, 1967, a U.S. space flight was hailed by *The New York Times.* "If present indications are confirmed, Surveyor 5 has made one of the fundamental discoveries of the century . . . Surveyor 5 has performed a notable feat." The Chicago *Sun-Times* commented, "The discovery that much of the moon's surface may be similar to that of the earth ranks as one of the major scientific discoveries of the century, if not of history. . . ."

What the spacecraft had done was deposit, after a number of near disasters, a 6-inch box on the side of a cliff on the moon. This box was equipped with radioactive sensors that could detect the composition of the moon's soil. The information radioed back to various U. S. space centers was that at least part of the lunar surface is made of basalt, the volcanic rock found in many places on earth but primarily on the bottom of the sea.

A bulletin from the University of Chicago described an interview with Anthony Turkevitch, faculty member and principal investigator for the project. "He observed that the relative abundance of chemical elements on the moon . . . indicated that the moon underwent a period of melting from great internal heat. And, Turkevitch added, while the melting appeared to be obvious, 'it is not possible to say at present whether that occurred on the moon itself or on some parent body.' "

An additional dimension of the moon became apparent during the flight of Lunar Orbiter 5 in 1967. Whenever it passed over one of the five great areas called "seas" on the moon's surface, it speeded up. The thought is that it was caused by a sudden gravitational pull caused by heavy bodies buried deep beneath the surface of the seas. Presumably these heavy bodies are the remains of enormous meteorites with iron cores that crashed onto the moon, causing the seas and their high craters as they splashed.

These sudden, irregular spurts of gravitational force could cause difficulties in navigation during future moon flights. The Apollo 8 satellite seemed to have no difficulties with navigation during its near-perfect orbits around the moon during Christmas week, 1968. It did receive criticism from people who, while applauding the astronauts and the engineering brilliance of the endeavor, questioned the use of a sum like $21 billion for such a project. Could not all this money been better spent rebuilding American slums? The answer must be a "perhaps," with the addition that no one had the idea of spending such a sum in that way, and Congress would certainly not have approved the appropriation if they had.

The other complaint was that the flight did mankind no good. It had no scientific purpose. "It's nothing but technology." Such critics fail to realize that modern science is helpless without advanced technology. Even Galileo could have done little without his telescope. What would be known about the ocean bottom today without automatic depth recorders? The reversals of the earth's magnetic field and all that implies could not have been found without magnetometers. Without radioactive dating, anthropology and paleontology could not have made the many advances recorded in the past few years. The moon shots are not less valid scientifically because they depend so heavily on instruments. Landings on the moon, according to Sir Bernard Lovell, prominent English astronomer, prove that "Our civilization is still virile." They should also answer many questions that will provoke the scientists to ask many more. Sir Bernard calls this "the unfolding of the human spirit."

Has the moon as an independent body ever been volcanically active? Is it dead or alive today? On October

11, 1968, the learned magazine *Science* carried a story by Air Force scientists which said that during the moon eclipse of April 13 infrared photographs showed a hot area in the satellite's Sea of Humors.

A meeting of the International Astronautical Federation, also taking place in October, 1968, produced more statements about spacecraft observations of the moon. Dr. Harold Masursky of the U.S. Geological Survey reported that the side of the moon which faces the earth is a basin resembling the basin of the Pacific Ocean. Orbital photographs show great cracks on the surface, lined with craters, where lava has very clearly erupted. He compared a large moon crater called Tycho, which has a mountain in the center, with a similar crater and mountain found in west Texas. Could these craters have been formed by meteorite impact? Could the effect be compared to the moment after a stone is thrown in the water when outgoing waves rush back for a moment to form a splash that rises up in the center? Could this splash have solidified into a mountain? Drilling for oil in the Texas crater similar to the moon's Tycho produced no evidence of volcanism beneath the surface. Yet Dr. Alexander Mikhailov of the Soviet Union argued that Tycho and its central mountain were volcanic and showed an air photograph of a crater in Indonesia that looks exactly like Tycho and has a smoking peak in the center. Dr. Masursky agreed that the moon has volcanic features but that craters which look like Tycho are obviously caused by an impact explosion.

Samples of the moon's surface taken directly by human astronauts should add a great deal to our knowledge of the origin of our satellite. Since the moon may have no erosion, and, if it was part of the earth in the distant past, these samples should give valuable news about the moon itself

and suggestions about the nature of the earth before the surface became smudged by billions of years of weathering.

If the sun tore the moon from the earth, imagine the raw, bleeding hole it left behind. An amputation on perhaps one-quarter of the earth's surface; what a wound to be repaired! Its depth, then, can only be guessed at present. If Darwin's idea is correct, then the hole where the Pacific now lies must have been hundreds of miles deep. The crust of the earth was more fluid then, if not quite molten. The newly formed moon so close at hand must have caused enormous earth tides and ocean tides, too, if water then existed. Erosion on such an unsettled surface must have been swift, and the earth finally corrected the imbalance of the enormous hole and became more or less of a globe again. It is difficult to visualize such wild events, yet the moon *does* exist. And there is an enormous scoop out of the earth that holds the water of the Pacific Ocean.

Dr. Robert S. Dietz in *Seven Miles Down,* an account of the bathyscaph *Trieste*'s descent in the Marianas Trench, discussed Darwin's idea sympathetically. Then he offered the idea that, perhaps:

There is still another intriguing hypothesis. Might not the earth's crust have been crushed and fragmented by the impact of asteroids walloping the naked earth? Eons ago a planet existed between Mars and Jupiter but it broke up for some unknown reason to form the asteroidal belt of microplanets. These asteroids with "safe" circular orbits still survive but the many eccentric ones were swept up by the earth and the moon.

When Galileo turned the first telescope toward the moon, he named the dark regions "maria" or "seas." We now know that these seas contain no water, for the moon's gravity is too

small; any water vapor generated by her hot springs soon escapes. As depressed regions of dark rock, the maria do closely resemble ocean basins. Most astronomers agree that Mare Imbrium and others were created by asteroidal impact. Could not our own ocean basins be of similar origin with the evidence largely erased by erosion?

In his text *Submarine Geology* Dr. Francis P. Shephard of the Scripps Institution of Oceanography found that George Darwin's theory "still has some appeal." He does, however, find the existence of Australia hard to reconcile to the idea. Commenting on Dietz's theory of asteroid impact, Shephard said, "The round shape of the Pacific and Arctic basins, which compare with the mare of the moon, is suggestive of such an origin. If this hypothesis can be substantiated the Atlantic and some other parallel basins may be explained by continental drift in the formative stages following the asteroid impacts."

The Darwin and Dietz theories show the complex interplay of scientific ideas. A man begins by having an idea about the origin of the moon and ends up proposing a mechanism for the existence of the Pacific floor. Taking up where the first left off, another man suggests that the first may be right and, with the addition of a new concept (continental drift), the existence of all oceans might be explained. No truly original concepts exist. New thoughts are merely built on the blocks of older ones.

III.

The Oceans, Born Yesterday?

IT seems presumptuous to ask the ocean why it exists and where it has been. While lulled by the rhythmic sound of waves breaking on the beach as you bask content under a summer sun, sailing on the dancing waters of some bay beneath a cloudless sky, steaming for days or weeks across the broad Atlantic or broader Pacific, the ocean seems immutable, as solid as the mountains. And, in one lifetime, the features do not recognizably alter. Therefore it seems reasonable to accept the obvious. But curious people unsettle this feeling of changelessness by finding marine fossils high in the Alps and the Himalayas, ocean sediments a thousand miles from the coast, and evidence that Virginia Beach may once have been near Dakar in Africa.

Available information now makes it clear that the ocean does have a history, and has undergone vast changes in the past. The complex story may be easier to understand piece by piece, even though in fact many different events have been going on at the same time and most of them interact. Why the ocean contains water seems one of the simpler problems needing solution.

Some years ago a brightly illustrated children's book

showed how the water got into the sea. It came as rain, falling heavily on a whole cluster of the most fiery, smoky, the most active volcanoes one can imagine. This book did not explain how the water got into the sky. In *The Sea Around Us* Rachel Carson wrote "... when the moon was born there was no ocean. The gradually cooling earth was enveloped with heavy layers of cloud, which contained much of the water of the new planet.... As soon as the earth's crust cooled enough, the rains began to fall. Never have there been such rains since that time. They fell, continuously, day and night. They poured into the waiting ocean basins, or, falling upon the continental masses, drained away to become the sea." This description is dependent upon the theory that the earth began as a mass of whirling gases in which the heavier parts settled to the core while the lighter gases such as ammonia and methane became the atmosphere. This idea of the earth's original atmosphere derives from the observation that some of the larger planets, farther away from the sun, are surrounded by these gases. The same situation may be presumed for the infant earth but no proof has been offered. Miss Carson's rainfall is quoted because it is such a vivid picture of a widely held concept, but it avoids the basic question by providing ready-made water. Perhaps a world without water is so inconceivable to us that people simply presume it has always been here.

For those who demand a source of water that arrived some time after the earth had began its independent existence, the observed action of volcanoes has been providential. Volcanoes spew out water vapor, carbon monoxide, carbon dioxide, nitrous oxide, and perhaps other gases, producing water for the seas and atmosphere. They must have been doing this through most of geological time. In 1943 a new Mexican volcano near the village of

Paricutín erupted in the middle of a cornfield, to the surprise of the man farming it. Scientific measurements showed that the Paricutín Volcano produced 16,000 *tons* of water each day. If this is an average, and considering the vast number of volcanic eruptions that have gone on since the beginning of time, gases released in this way from the molten magma of the earth's interior seem sufficient to explain all the water we find on the surface today. Now scientists generally accept the explanation that most earthly water originated from volcanoes.

Dr. Roger Revelle, Director of the Scripps Institution in 1955, proposed a water theory that would have ingeniously solved a number of Pacific problems all at once. Revelle suggested a massive series of volcanic explosions about 100 million years ago. These covered the Pacific Ocean floor with volcanic basalt, wiping out all evidence of the past, and that is the reason no sediments can be found for older ages. The volcanic outpourings were so great that the ocean floor collapsed. This would explain why guyots, the flat-topped volcanic seamounts that must have once been at the sea's surface (they must have been eroded to become flat), now lie beneath more than one-half mile of water. Along with all the magma released, great quantities of water came forth. The ocean's volume may have been increased by as much as 25 or 30 percent.

This water did not establish free oxygen in the atmosphere. Free oxygen is necessary for the existence of almost all life as we know it. How free oxygen was created is a separate, very interesting problem.

Ever since the days of the English astronomer, Edmund Halley (most famous for the comet he predicted in 1682), people have been trying to judge the age of the ocean by its salt content. They reasoned that the original water

must have been fresh, since neither rain nor volcanic gases contain more than microscopic amounts of salt. Today the average sample of sea water is about 35 parts per thousand common salt. How long did it takes the sea to become so salty? The salt must have arrived by way of rivers carrying salt eroded from the land and the rocks.

The change in sea composition would be gradual. In the system generally named the "hydrologic cycle," though perhaps the word should be "circle," almost all of the rain that falls on land finally reaches the sea, carrying with it a variety of sediments including salt. In the sea, evaporation carries fresh water away, almost, if not entirely, cleansed of its salt. The cycle has repeated itself over the endless stretches of time since water first appeared.

If one knows the total volume of sea water, the average amount of salt in it, and the annual flow of rivers, it should be possible by simple arithmetic to judge the amount of time it has taken to achieve the saltiness we now know.

The reckoning involved in this computation must have been tedious but the idea is beautifully simple. It also has certain flaws. The rate of erosion cannot have always been the same as it is today. When the continents were lower and flatter the rate would be slower. Large areas of the sea, such as Great Salt Lake, have been isolated. The water in such areas evaporates, leaving huge deposits of salt that are withdrawn from the total budget. With these fairly large factors in mind, the method has been tried and produced an age for the oceans of at least several billion years. Although this agrees in a general way with geological evidence, it is not supported at all by evidence from the bottom of the sea itself.

At one time or another, if the presence of marine fossils means anything at all, most of what we now know as land has been covered by the sea. Exceptions may be the

Laurentian hills of Canada, parts of central Africa, and perhaps some of the Antarctic, a land that yields its secrets slowly. Other exceptions may also exist, but certainly there are few of them.

The seas that once lay over today's continents were probably not deep seas. Maybe there were only ten feet of water on them, possibly a few hundred, but the essentially granite continents, once formed, were seldom under abyssal seas, seldom under many thousands of feet of water.* According to present theory, they could never have been because the granite of which continents are made is lighter than the basaltic rocks which cover the deep bottom of the ocean. Continents must float high; high above basalt, but not necessarily above sea level.

Considerable evidence shows that the level of the sea has changed substantially, up and down, at least thirty times in the past. Continents rise and subside due to pressures beneath them or new weights, such as mountains or ice sheets, above. Continents are often eroded so close to sea level that the change of a few feet in the sea may cause a deep invasion. The sea has left innumerable calling cards on land, and this is one geological fact about which little doubt exists. *Why* the sea level has changed is quite another story.

The sea leaves its records, and these can be deciphered; but the task is made somewhat difficult because much evidence has been eroded, covered by lava flows, or deformed in the process of mountain building. Sediments on the bottom of the sea must be a much better record of past events, if only because erosion, the greatest destroyer, is at a minimum. Sedimentary rocks on land tell of happenings very long ago. Sediments on the bottom of the

* An exception to this may be the Phosphoria Sea that once covered what is now Idaho and the states bordering it.

sea should be even more informative. The startling thing is that *truly ancient sediments have so far been impossible to find anywhere under the ocean.* Using this evidence alone, the oceans we know today must be, relatively, very new developments.

Are they all equally new, or is the Pacific Ocean older than the Atlantic? It was once thought to be, as its floor was once thought to be of different composition. Certainly if George Darwin's theory is correct, then the Pacific must be the senior.

Without reference to Darwin's theory, the U. S. government's National Science Foundation discussed the age of the Pacific Ocean basin in its 1966 report.

Until recently, the oldest rocks collected from the ocean basins were of late Cretaceous age, about 100 million years old. However, on land the geologic record shows sedimentary rocks at least 2 billion years old. But these rocks, although they are of undoubted marine origin, were deposited in comparatively shallow water, such as that presently covering the continental shelf or under the shallow seas that once covered the interior areas of continents.

Does this mean that the present ocean basins are only about 100 million years old? Were there deep sea basins throughout the history of the earth or were all the earlier seas shallow? These questions may be answered by the continuing search for older sedimentary rocks in the deep oceans.

During the 21st cruise of the *Vema,* scientists from the Lamont Geological Observatory of Columbia University found evidence that pushes the age of the Pacific Ocean back at least to 175 million years.

A core collected from the Shatsky Rise (31° 51′ N. 157° 20′ E.) between the Emperor Seamount chain and the Japan Trench is of early Cretaceous age, 106 to 110 million years old—the oldest sediment thus far removed from the ocean basins. By using a seismic profiler [a device similar to an echo

sounder, that probes for reflecting layers in sediments] it was found that these old sediments, that have been uplifted and exposed at the core locality, dip down and are covered in adjacent basins. Moreover, the profiler records indicate that at least 200 meters [650 feet] of older sediments lie between the lower Cretaceous beds and the harder basement rocks.

Deep sea sediments of the type found in the core accumulate at a rate of about 0.1 inch per thousand years. At this rate 200 meters represent 60 to 80 million years of deposits, giving a minimum age of about 175 million years for the Pacific Ocean basin. It may even be much older, for the inferred "basement" may in fact be harder consolidated sedimentary rocks.

This new evidence has important bearing on ideas of the age and origin of ocean basins in general. The relatively thin layers of sediments above the harder basement in the deep seas are only about 0.5 kilometer [1,640 feet] thick in the Pacific, and but slightly thicker in the Atlantic Ocean basin. Assuming that the rate of oceanic sedimentation has held fairly constant, all of this sediment could have accumulated in the last 100 million years. If the Pacific is at least 175 million years old, either the *assumptions about rates of sedimentation* [Author's italics] *must be altered* or older sediments that may go back much farther into geologic times are buried in the recesses of the deep. The Foundation-supported Deep Ocean Sediment Coring Program may throw light on this question.

Several observations seen permissible about this admirable summary of a very important problem and arduous project. In order to put the Pacific basin back to 175 million years, it is necessary to assume a regular rate of sedimentation; yet, as was pointed out in the problem of dating the ocean by its salt content, such an assumption is very risky and may very well be untenable. Even dating the Pacific back to 175 million years leaves the researchers with a very considerable gap. If this is the best they can do, how do they account for the remaining four billion

years of earth time? Where was the Pacific then? The same question arises when discussing the age of the Atlantic basin.

Of all the great oceans, the Atlantic has undoubtedly been the most intensively studied because a number of highly developed maritime nations surround it. Many thousands of samples of the Atlantic sea floor have been taken and analyzed. Leaders in these efforts have been the ships of the Woods Hole Oceanographic Institution in Massachusetts, and, after 1949, those of the Lamont-Doherty Observatory in New York. Dates from core samples have become progressively older. The 1948 record age was 60 million years from a sediment sample on an Atlantic seamount. Successive cores have gone farther and farther back; yet, as of this writing, none have been recovered that can be dated to a more remote period than that of the Jurassic, about 150 or 160 million years ago. And there is only a single such sample. How old will the Atlantic basin finally turn out to be?

Finding the age of any ocean bottom may involve several different techniques. The earliest method was simply to dredge the sea floor with one of a variety of big scoops. The historic British *Challenger* expedition, a four-year oceanographic cruise that began in 1872, sent dredges down thousands of feet to recover samples of the bottom surface. Dredging is still used frequently but, since it only scratches the top, the samples will only help determine the composition there and the recent history of the sea floor in question.

Coring, using devices that in principle resemble the tool you would use to core an apple, was another early development in ocean-bottom exploration. Coring instruments have now been perfected to the point where samples of the sea floor as much as 100 feet long have been re-

covered. A core this long will contain sediment many millions of years old. Dating of the samples can be tried by the comparative methods of the geologists, by dating any fossil shells on a well-worked-out scale which tells when they flourished, by measuring the half-life of their various kinds of radioactivity, or by testing their magnetic polarity against the tables now being worked out. Deep-sea cores have produced a great deal of valuable information. They have a major drawback however. Cores will not penetrate very far on a hard rock bottom.

To determine the complete depth of the sediment, the thickness between the apparent bottom and the true basalt floor of the sea, oceanographers use a method known as seismic profiling, first introduced for this purpose by Dr. Maurice Ewing. He adapted it from a sonic method of testing underground structures first employed by oil prospectors.* Knowledge of sediment depth derived from seismic profiling gives some indication of the age of deposits (the specialists can recognize characteristic profiles of various periods and epochs traced on the recording graph) but by no means does this give an absolute age of the deposits. And it will not give the age of the sea floor itself.

The latest development in the attempt to write the history of the oceans is deep-sea drilling, once again using technology developed by the oil industry. The most ambitious use of deep-sea drilling so far has been the Atlantic-Pacific ocean expedition of the *Glomar Challenger*. The Deep Sea Drilling Project, of which the *Glomar Challenger* is the major instrument, has objectives no less than cosmic. Going beyond the single question of the age of the oceans, the sponsors hope it will provide information about:

* It depends on timing the return of echoes from shock waves generated by an explosion as they reflect back from the junction of layers of different densities.

The long record of the earth's climatic history.

The history of the major ocean current systems and water masses.

How and when the ocean basins attained their present configuration.

Changes in the earth's magnetic field.

The composition and rate of accretion of cosmic particles embedded in the sedimentary rock.

The origin of extraordinary concentrations of metallic oxides, such as the manganese nodules found widely on the ocean floor.

The evolutionary history of shelled, one-cell plants and animals, including the profound changes in these organisms that occurred about 100 million years ago.

The practice of punching holes into the sea, to produce oil wells, began rather modestly in the 1920s. One of the areas in which the industry pioneered was Lake Maracaibo, Venezuela, a salty inlet of the Caribbean Sea, and early drilling was seldom in more than 100 feet of water. Geologists and engineers found much encouragement in the oil field of Lake Maracaibo. It developed into one of the greatest producers of crude oil the world has ever known. Why oil concentrated there in such abundance presents one of those mysteries.

Underwater exploration for oil profits advanced slowly until after World War II, because abundant crude oil existed on land and prices stayed low during the Depression. Then, after World War II, demand began to exceed supply, and the oil industry turned to the sea in earnest. Wells went down in deeper and deeper water, the drilling skills keeping pace with the increasingly ambitious goals.

Science, of course, shows no profits that encourage investment in it and so must often borrow from industrial technology. Science also depends on the unpredictable

favor of government. Impressed by the new drilling methods being developed by the oil companies, scientists proposed that these new methods be used to drill deep into the earth, below the granite and the basalt, to discover what is down there, and by testing sediment samples on the way down, perhaps three or more miles below the sea floor, answer many questions about the history of this planet. They named the big project the Mohole. After years of study and considerable expense, it seemed that the Mohole project was about to begin in earnest. Congress need only appropriate the money. As many bitter people know, Congress failed to do this. Congress denied the Mohole scientists something less than $100 million, which might have unlocked countless secrets buried beneath the surface, but voted $5 billion to send astronauts rocketing around the earth in orbit in a game of one-upmanship against the Russians. (The cost for this has now exceeded $20 billion.)

To serious researchers, such a shortsighted decision did not come as a complete surprise. Even before the Mohole program received a political stiletto, men from Scripps, Woods Hole, Lamont-Doherty, and the University of Miami in 1964 had joined together on another project to go deep into the earth. Since drilling is so expensive, men from the four institutions decided to pool their resources. They formed an organization they called the Joint Oceanographic Institutions Deep Earth Sampling. In practice, they call it JOIDES.

The first undertaking of JOIDES began in 1965 when it was learned that a drilling vessel, the *Caldrill,* chartered by the Pan American Oil Company, was due to sail from California to Halifax, Nova Scotia. The group arranged to hire the ship for a month while it was on its way. They

chose to have the *Caldrill* work for them on the Blake Plateau, an unusual geological formation off the coasts of Florida, Georgia, and South Carolina. The Blake Plateau, averaging about one-half mile in depth, is neither continental shelf nor deep sea. Hardly anything else on earth resembles it, and the reason for its existence has not been satisfactorily explained by geologists.

The drilling started in comparatively shallow water off the city of Jacksonville, Florida. Ultimately it moved to a position where the water was 3,500 feet deep. The deepest hole dug was 1,050 feet below the ocean bottom, at that time a record for scientific work. None of the cores taken produced revolutionary changes in geophysical thinking. None were expected to. The main purpose of the first project was merely to discover if this kind of research drilling would be possible. After six successful holes, the pleased scientists involved said they could probably drill later in as much as 6,000 feet of water.

By 1968 the University of Washington had become a member of the JOIDES group and they had a new, 400-foot-long drill ship built especially for them, and financed by the National Science Foundation of the U. S. government, ready to go into action. Instead of a mere 6,000 feet, the *Glomar Challenger,* thanks to the pace of technology, began work where the water was 11,720 feet deep. The area chosen, the Sigsbee Knolls in the Gulf of Mexico, had been shown by depth-sounding instruments to contain many salt domes. Salt domes interest geologists because they often act as a trap over pool formations of oil. After drilling only 472 feet into the sediment, the *Glomar Challenger* struck oil, although this was not the objective. The scientists ordered the hole capped to prevent pollution from seepage and the position was carefully marked.

No one had ever known that oil could be found under such deep-sea conditions. Where and how it formed remains to be discovered.

The second major drill site was east of San Salvador Island in the Bahamas, chosen because a core there had already produced the oldest sediment ever taken from the Atlantic. It dated from the early Cretaceous, perhaps 135 million years ago.

The drill in the Bahamas penetrated 2,500 feet below the bottom. A press release about the first cruise on this project said, in part:

> Sediments of late Jurassic age, 150-165 million years, were obtained. These are far older than any previously taken from the deep sea, and far older still than those shown by the seismic profiler records to lie between the depth reached and the basement rocks. . . .
>
> In this area it was found that deep sea conditions much like those found today prevailed here for at least the last 150 million years, that beneath these are much older sediments which place serious limitations on theories of Continental Drift by sea-floor spreading. . . .

Scientists in charge of the second leg of the drilling expedition, from New York to Dakar, made statements at the end of the trip that indicated the experiments were definitely supporting the idea of drift. Coring began near Bermuda and the quite thick sediments were dated as about 85 million years old. Approaching the Mid-Atlantic Ridge the cores became shallower. Within 100 miles of the crest, scientists estimated the sediment was 18 million years old. On the crest itself, hardly any sediment existed at all, suggesting the youth of this part of the ocean floor. The sediments became thicker as the *Glomer Challenger* approached Africa. Other evidence suggested that the

Ridge had grown considerably higher over the last millions of years.

On the third leg, from Africa to Rio de Janeiro in Brazil, cores produced more confirmation of the idea of sea-floor spreading. The findings suggested that Africa and South America began to separate 150 million years ago, presumably a motion independent from that in the North Atlantic since the dates, though ancient, do not precisely match.

The fourth leg took the drill ship from Rio de Janeiro to Panama. From a core in the Vema Fracture Zone, at least 1,000 miles from the South American coast, no sediments older than 500,000 years were recovered, and this sediment obviously came from the Amazon River. The youth of this sediment may confirm the idea that fractures are geologically short-lived; they fill up and disappear. A core from the bottom north of Barbados produced rocks exactly like those found beneath the coral-covered surface of the island. This adds weight to the idea that Barbados is not part of the chain of West Indian islands but a block of the deep ocean floor that has been raised from more than three miles down by underground forces. Much of the floor of the central Caribbean turned out to be chert, a hard flinty rock also frequently found at the bottom of the North Atlantic but missing from the South Atlantic. This strongly suggests a kinship between the Caribbean and the North Atlantic and that the North and South Atlantic Oceans have not always been joined together.

While this massive drilling project went on, other drift theorists, of course, did not remain idle. Dr. Edwin Karp of New York University, for instance, suggested that drift and ocean-floor spreading could be tested by bouncing radar signals off the moon.

This procedure would measure very minute changes

in the distance between various islands in the Atlantic. The tool would be a radar interferometer, an instrument than can give very precise measurements of very small distances. In practice, a radar signal would be sent from one island station to the moon, then bounced back to earth and to a receiving station on an island a considerable distance away. Dr. Karp believes that this system could tell whether the two islands had moved farther apart, or closer together, by differences as small as one-half to two inches per year. (This is the rate at which it is proposed the oceans are spreading.) Any change in the distance between the two islands would show that the sea floor is in motion.

Since the island proposal to check continental drift was made, the Apollo 11 feat of placing a laser reflector on the moon has made the experiment possible in another way. The laser is an extremely intense beam of directed light that can pinpoint distances within an accuracy of a few inches. Laser beams from earth can now be directed to the reflector the astronauts left behind and, over a period of a few years, any change in the relative location of the laser sender and receiver can be discovered. If the beam now being sent from California turns out to be moving several inches to the west every year, in relation to the reflector on the moon, that would be a very good indication that North America is drifting. Similar experiments with lasers will be performed from other positions on the earth in order to obtain a cross-bearing from several points.

Among certain scientists, particularly some of the older ones, there seems to be a determined effort to discredit the idea of continental drift. It may be that when they were students, perhaps twenty or even more years ago, such a prejudice against it was taught that they find the hypothesis almost impossible to accept. As mentioned earlier,

Bruce Heezen pointed out that before 1955 no U.S. geophysicist would dare speak seriously about drifting. The Deep Sea Drilling Program is an exhaustive and scrupulously fair research effort that may finally settle the controversy once and for all.

IV.

The Incredible Bottom

MEN made the last great achievements in land exploration, the conquest of both the North and South Poles and the ascent of Mount Everest, under inhuman conditions of cold, inaccessibility, terrible, dangerous terrain, and, in the case of the mountain, lack of oxygen. The conquerors reached these pinnacles not because any very new instruments had been developed to aid them, but because the men had physical endurance, courage, good planning, and teamwork. They took it for granted that they could see where they were going.

On the new frontier now gripping men's imaginations, the bottom of the sea, all the same hazards exist, with an additional handicap. The goal is essentially invisible. In very clear tropical water one may see as far down as 80 feet. The last rays of light from the surface disappear entirely 600 feet below. Although deep-diving research submarines do carry powerful searchlights, their beams can illuminate only the area immediately surrounding the vessel. No one will ever be able to get a look at the whole ocean bottom, since, and this can be said with assurance, no one can ever remove the average two miles of water that cover it.

Considering the problems, it should surprise no one that only two percent of our last frontier has been surveyed in any detail at all. Nevertheless, maps to help visualize the invisible have been made. They are based entirely on soundings, measurements of the distance between the floor of the sea and the surface. In the old days when soundings were taken with a piece of lead on a line dropped over the side, and each depth far down required hours to determine, no one could accumulate enough figures to draw a picture. With the development of automatic, sonic depth recorders in the 1920s, the number of accurate figures began to accumulate at a meaningful rate. The German research ship *Meteor,* up through 1938, did a number of detailed surveys of the North and South Atlantic using the new recorders. The *Meteor* figures are now one of the foundations for the modern view of the basins. (It was feared that some of the German data was lost during the bombings of World War II, but most of the material has since been recovered.)

Oceanographic research expanded enormously after World War II. A constantly growing number of U.S. ships sailed the seas looking for answers to scientific questions. Many of them took continuous readings of the bottom depth wherever they traveled. Finally, in 1957, Bruce Heezen and Marie Tharp of Lamont-Doherty felt that enough information existed to draw and publish a "physiographic diagram" of the North Atlantic Ocean. The following year, through the American Geological Society, they published another one, this time of the South Atlantic. They carefully stated that the diagrams were by no means complete, might contain inaccuracies due to poor soundings, but that they were bringing these out to stimulate others into improving on their work. A diagram of the Indian Ocean followed in 1964. Mean-

while, H. W. Menard of the Scripps Institution prepared a somewhat similar diagram of the North Pacific. In 1968 Heezen and Tharp brought out a revised North Atlantic diagram and helped the National Geographic Society prepare a picture, somewhat simplified, of the whole Atlantic Ocean Floor which the Society mailed along with the June, 1968, issue of their magazine. Until these recent publications no one could possibly have had any overall idea of what three-quarters of the globe really looked like. And the mapmakers had no idea until they assembled all their depths to discover what could be made from them.

Without any Gallup survey to back up the statement, it still seems safe to say that, should they think about it, most people would presume the sea floor is flat. They may infer this from the flatness of the surface. Men have sailed the seas for all their adult lives without realizing they have been passing over a wild array of features ten times as dramatic as anything to be seen on land.

From a purely visual point of view, nothing rising off the sea floor looks like the same sort of thing on the continents. A single mountain range dominates a picture drawn of the bottom. Its discoverers claim this mountain range goes around the world two and one-half times, a distance of 40,000 miles. Called the Mid-Ocean Ridge, it is 1,400 miles wide across the Atlantic. In this ocean the Ridge lies midway between the Americas and Europe-Africa. Its peaks are highest in the center and very jagged, since hardly any erosion exists to soften them. Between the highest peaks there runs a deep valley known as the Rift. It is most pronounced in the Atlantic where the valley may be 15 or 20 miles wide and 6,000 feet down between sheer cliffs reaching to the peaks. The Rift valley also makes itself evident in the Indian Ocean. Marie

Tharp, now preparing a diagram of the South Pacific, so far finds the Rift less pronounced inside the rise of that ocean but still perfectly clear. On the other hand, a number of oceanographic expeditions looking for the Rift in the Pacific have been unable to find it.

The Atlantic Rift is bisected by numerous deep fractures running at right angles to the mountain chain. These fractures sometimes move the Rift off its main line to the east or west by hundreds of miles. On the National Geographic diagram, perhaps a little bit too dramatic, the Ridge looks like the skeleton of an extremely long fish, with a back broken in numerous places. Considering man's exploring nature, it seems amazing that the extent of this very major feature of the earth was only realized in 1956.

The Mid-Ocean Ridge obviously represents some sort of worldwide system that reason and research should finally explain. Another dramatic feature of the sea-floor pictures are the seamounts. These rise straight up from the bottom, without foothills, and, certainly volcanic, their peaks are almost perfect cones. Seamount names usually derive from the ships that discover them. The largest so far sounded in the Atlantic is the Meteor Seamount which rises in majesty 15,600 feet from its base. Some seamounts perplex oceanographers because their tops are flat. Since the flat-top seamounts are usually down in about a mile of water, it is difficult to see how erosion could have worked to wear off the characteristic volcanic cone. The flat seamounts were named "guyots" by a Princeton geologist turned Navy officer, named Harry Hess, who first discovered them in the Pacific during World War II. The cause of guyots has been the subject of numerous scientific papers.

Of the other structures in the ocean, the continental

slopes seem most dominating. These gigantic cliffs, sometimes called escarpments, are "by far the steepest, longest and highest topographic feature on the earth's surface." * Continental slopes average 12,000 feet above the ocean floor and near deep ocean trenches they may stand as much as 30,000 feet high. For almost half their length around the world they are adjacent to trenches. The degree to which they drop resembles the sides of the steepest mountains. The most abrupt continental slope in the world drops off the southern coast of Cuba. The average angle of the cliff is 17 degrees and in places it drops at an angle of more than 45 degrees. Continental slopes separate the granite continents from the basalt floors of the sea. Dietz calls them "the true geologic boundaries of the continents." On the diagrams they stand out magnificently. What an awesome tourist attraction they would be, if only one could get a complete look at them.

Also prominent on the diagram are the arcs of islands, rings of volcanoes, atolls, continental shelves, fractures not connected to the Ridge, abyssal hills, abyssal plains, and submerged canyons deeper than the Grand Canyon of the Colorado. That the origin of most of these things still lies in the realm of speculation is not to be wondered at. Abyssal plains, for instance, must have existed for millions of years but the scientists only found them in 1949. Attractive theories are being formulated quite regularly to explain all the wonders that have been turning up with great frequency on the bottom of the sea. Some of the theories will certainly survive. Others will succumb under the weight of contradictory evidence sure to be produced as more and more explorations are carried out.

* Robert S. Dietz, *American Scientist* (March, 1964).

Any agreements scientists reach about the causes of the peculiar features of the ocean bottom will have to take into account the fact that it is different from the continents. Not simply is it under water, its floor is made of heavier rock. As mentioned before, continents are mostly granite while the sea floor is almost entirely basalt, a difference in kind, not one of degree. Much of the continental surface may be overlain by rocks made from sediments or metamorphic rocks that are a mixture of several types, but it is granite that supports these rocks. Ocean floors may also have sediments and mixed rocks (sandstones, mudstones, limestones, and such) imposed on the base but the substance underneath it all is constant. Both granite and basalt originate as igneous rocks. They came hot and fluid to the surface as lavas from subterranean magma. They differ chemically and thus in weight; presumably why one always lies on top of the other.

Continents are always very distinct from ocean basins; but thirty tiny exceptions to this rule lie in the Indian Ocean about 700 miles east of Africa. These are the humid Seychelles Islands which the British and French have fought over in a desultory manner for more than a hundred years. The Seychelles geological claim to fame is that they are made of granite. They have been dated by radioactive methods as about 600 million years old. How could purely continental, little rocks exist so far away from land, surrounded by water 12,000 feet deep? The most reasonable explanation is that somehow both India and Africa abandoned this little bit of earth when they separated, like crumbs left behind when a piece of toast is sliced. The existence of the Seychelles is one more argument in favor of continental drift, even though a small one in point of size.

The word "basalt" apparently had an Ethiopian origin.

It meant black stone. On land, in the United States, basalt can be seen in the solidified lava fields of the Columbia Plateau in Washington and Oregon. Because the surface of this bleak area was considered to resemble the surface of the moon, the Columbia Plateau was used as a training ground to acclimate astronauts preparing for their lunar voyage.

The word "granite" derives from the Latin "granum" or grain. The rock ordinarily consists of feldspar, quartz, and mica. Although one-third less dense than basalt, it is still a very tough substance frequently used in architecture and gravestones. Parenthetically, basalt underlies all continental granites as well as all sea bottoms.

The scientific literature throws little light on the question of why magma produces different kinds of material. There must be some significance, however, in the fact that there have been no recent flows of granite. Most of it is Pre-Cambrian in age. Basalt, on the other hand, is produced somewhere on earth almost every single day.

According to the moon theory of Sir George Darwin, our planet may originally have had a complete crust of granite until the satellite broke off due to the sun's gravitational pull. The remaining granite surface would have been in pieces, like broken pavement, but these finally settled into place as the continents. A more contemporary idea is that, when the earth was still molten, granite floated on the surface like scum and only became fixed when the surface cooled. A variation on this is that the lighter rock worked its way to the surface over the ages and now rests in equilibrium or isostatic balance. Now the continents and their mountain ranges are higher than the sea bottom simply because of their relative weight. They float on the basalt like icebergs in the sea. Like icebergs, they are mainly below the surface. That would

be why the distance to the core of the earth is greater under the land, and in particular under the mountains, than it is under the sea. The granite pushes the basalt down, increasing the total thickness. It was for this reason that the Mohole was to be dug in the sea rather than on land. The distance was shorter.

Regulation maps are printed with a great deal of blue ink over what, at least to geologists, is not ocean at all. It may be salty, lobsters and oysters may thrive in it, the storms may be fierce, but the root of this area is granite. Chemically, it is just like the land above the present water line. Called the continental shelf, it represents seven percent of the world's total marine area.

According to the most generally held theory, continental shelves developed when the oceans rose above their proper basins and flooded low-lying parts of the land. International law defines continental shelves as extending out to the 100-fathom curve, the line where the water becomes 600 feet deep. Many maps and even navigational charts are drawn with such a line on them, as if such an exact depth truly existed all over the world. People generally think of the shelf as a smooth plain that drops gently to the much steeper continental slope, where it ends abruptly. Dr. Francis P. Shephard of the Scripps Institution has calculated that the average depth of the water at the shelf edge, for all parts of the world, is actually 432 feet. The difference between fact and legal fiction, of little importance before men realized the vast wealth that lies on and under the shelf, will no doubt one day create dangerous squabbles between sovereignties. When one nation begins to drill for oil on a bottom which another nation claims as part of its shelf, or seeks diamonds or gold there, diplomats will wish more precise charts of the shelves had been drawn.

The continental shelves of North and South America are of two very distinct types. Those on the eastern, Atlantic coast are quite wide. The shelf off Maine extends almost 200 miles from shore while that off Argentina is even wider. On the western, Pacific side, the shelves are very narrow and, off Chile, sometimes nonexistent. The differences, in part, are considered due to the fact that on the Atlantic side of the continents the age of mountain building has passed and the crust is stable. Products of mountain erosion have fanned out to create a broad plain. On the Pacific the mountains are new and still in the process of formation. On this coast the bottom keeps faulting at right angles to the coastlines and earthquakes are frequent. In a slightly different view, North and South America have been pictured as two vast ships plowing westward across the earth. The high coastal mountains are their bow waves. Whatever shelves may have existed now lie buried beneath the advancing mass. Off western South America what should be a shelf is actually a deep trench and the suggestion has been that the continent is actually sucking the sea floor underneath it and then pushing it up to add more material to the base of the Andes.

World wide, the most interesting fact about the continental shelves must be their almost uniform depth. This presumably relates to the uniform lowering of the sea level during the various Ice Ages. Water from the sea disappeared to form the great sheets of ice that covered the land. The ice may have been as much as a mile thick. Estimates of how much the level lowered vary considerably. The best figures range between 360 and 540 feet, figures that fit very well with Dr. Shephard's 432 feet as the present average depth at the edge.

At the height of the Ice Ages, when the maximum

amount of water had been withdrawn from the sea, the shoreline stood right at the edge of the steep continental slope. It remained there for thousands of years, long enough for the erosion on land and the sea action of waves and currents to produce a stable platform that still exists. Where glaciers existed, they probably moved out to the edge of the shelf, depositing their scourings of rocks and debris, thus gradually extending the width of the shelf in such areas. Where they have been glaciated, shelves are much wider than the world average.

Beyond the shelves, wide or narrow, stand those awesome cliffs, the continental slopes which descend almost to the deep ocean bottom itself. Why not simply accept them as one would the sides of a mold of Jello on a plate, or the side of a cliff as it stands above a river valley? Why do the shelves need explaining? The answer may be that scientists find another question beyond that asked of mountaineers. "Why do you climb it?" "Because it's there!" The scientists go on to wonder "*Why* is it there?"

The slopes are the transition point between the two major elevations on earth. Considering their importance they seem rather narrow, generally somewhere between 10 and 20 miles wide. One thought about their origin is that they have been caused by some catastrophe, such as the impact of large cosmic bodies. The slopes differ markedly, however, and thus could not have all been created at the same time. In addition, they show few signs of deposition or erosion, thus demonstrating that they are not geologically very old. Another idea is that slopes result from downwarping of the continents, that is, they are being pulled down to the ocean bottom. This would mean that segments of the land's granite now lie at the base, but such segments have never been discovered. Other ideas are that the slopes were created by wave

erosion or by faults in the crust normal between the light continental rocks and the heavier rocks on the ocean floor. A recent theory suggests that continental slopes result from the spreading of the ocean floor. As it expands away from its center in the Rift, the spreading floor pushes sediment against the continents in a manner similar to that postulated in mountain building.

The slopes are bisected in many places by undersea canyons, deep gashes that rival anything found on land. Normally one thinks of canyons as being caused by rivers. The most famous one in the world certainly owes its existence to the Colorado River. Deep-sea canyons do occur off many major rivers; for instance, the Hudson, the Congo, the Ganges, and the Indus. A number of other canyons, however, bear no relation at all to any existing river system. One, the Mid-Ocean Canyon, begins in Greenland and runs down the Atlantic, hundreds of miles from the nearest land, until it reaches the latitude of Baltimore, but in mid-sea. Most canyons occur on the continental slopes and are phenomenally deep.

The easiest solution to their existence is to say they were formed when the sea level was much lower than today and the rivers could perform their erosive work. Since some canyons are thousands of feet deep, this would require a change in sea level of a dimension not supported by any other evidence. To counter this, it has been suggested that the shelves subsided over the ages and that what are now deep canyons were once much closer to the surface.

A currently popular explanation of deep-sea canyons is that they were caused by turbidity currents, swift landslides from the shelf and down the slope, eroding mightily as they flowed. The turbidity current idea seems to assume that the canyons were all formed during the Pleistocene,

the last million years, but critics suggest that there could not have been enough and powerful enough currents to dig such deep gashes into granite during that period of time. (It might be added that no one has ever seen a turbidity current, though obviously some kind of sea landslides must occur.) Submarine canyons remain a puzzle.

The deepest, flattest parts of the ocean do not occur in the center. As a matter of fact, in the Atlantic, with a mountain range running right down the middle, the truly flat, deep areas usually lie rather near the continental edges, more or less under the continental slopes, but separated from them by an area called the continental rise. These areas are usually called the abyssal plains. They are amazingly flat, much more so than anything in Siberia or the Great Plains of North America. The sediments over the abyssal plains are thick, possibly the result of turbidity currents (landslides) that deposited vast amounts of material after racing down the continental slopes and finding the deepest accessible region of the sea floor. Comparable plains in the Pacific are relatively rare, probably because vast stretches of that ocean are too far from any continental slope to receive any substantial amount of land-based detritus. What would be abyssal plains in the Atlantic are, in the Pacific, regions of countless small hills, usually volcanic in origin. No doubt these exist in the Atlantic but many of them have been buried.

As an example of the many factors involved in a scientific hypothesis, these abyssal hills are instructive. One might announce on the basis of the fact that Atlantic deep hills are well buried, while Pacific hills are quite prominent, that the Pacific is obviously younger. Its hills have not yet been covered up by the passage of time. Such a simple bit of reasoning, of course, ignores all sorts of

other factors that enter into the matter. Science can seem very slippery unless everything possible is accounted for.

The Atlantic and the Pacific are very similar oceans. Both are founded on basalt (though it was thought, not too long ago, that their basement rock differed). Their average depth is much the same, though the Pacific may be just a little bit deeper. Why should the two major oceans of the world be any different from each other? After all, presumably, they are subject to the same forces of nature. Considering that they ought to be alike, it is extraordinary how much the two great bodies of water differ. The Pacific is twice the size of the Atlantic.

The Atlantic has few active volcanoes while, in select locations, the Pacific has many hundreds of fire mountains.

The Atlantic has one guaranteed atoll (in the Bahamas) yet they are almost uncounted in the Pacific.

One major arc of islands exists in the Atlantic (the West Indies) but they are very numerous in the Pacific.

The only major deep trench in the Atlantic lies north of Puerto Rico. The Pacific has many and they are all deeper.

The Atlantic Ocean has quite a few fractures of not very imposing length, and most of these extend out from the center at right angles to the median Ridge. The eight "great" fracture zones in the Pacific all seem to sweep outwards from the American continental margins and they move many thousands of miles toward Asia. Recent surveys have also produced a number of north-south fractures in the Pacific, which have no Atlantic counterpart.

The Pacific has great mountain ranges buried beneath the water and many guyots. The Atlantic has one great mountain range and comparatively few guyots. The greatest Pacific range does not lie just half-way between its

opposing continents but has a pronounced affinity for the coast of South America. If continental drift affected the Pacific (as it must have), its effects are still much obscured. If the Pacific has a Rift, it is either younger or older than that in the Atlantic.

To shed any light on the many mysteries involved, the world's two greatest bodies of water often need to be considered quite separately.

V.

Are Other Planets So Restless?

THE idea of a great, global rift, one of the major concepts that have made geophysics such a lively science in recent years, was originally an Atlantic idea. The Lamont-Doherty scientists who proposed it had been studying the great mountain range, the Ridge, that runs the length of that ocean. The first hint of the Rift came from soundings that seemed to show it lying between the highest peaks, at the center. Then a plot of earthquake epicenters seemed to show a great number of tremors along the same line. Oceanographic cruises helped confirm the thought. The Rift showed up on new soundings where predictions said it would appear. Magnetometer readings showed that the force of the magnetic field in the Rift was much greater than in the areas to either side of it. Thermal probes showed that relatively large amounts of heat were emerging from the floor of the Rift. Seismic profiles demonstrated that the sediment there was remarkably thin.

In the Atlantic the Rift comes ashore at a number of islands, including Tristan da Cunha, the Azores, and Iceland. In Iceland the Rift can actually be seen. Here there is a miles-long trench, called a graben, that is some-

times 40 feet deep. Its slow expansion is being measured. The three islands mentioned have all had active volcanoes within the last few years, as well as many signs of earthquakes.

Plots of earthquake centers were also extended into the Indian Ocean, and, with some success, were shown to relate to known submerged mountain ridges. After the Atlantic Ridge makes a big loop around South Africa, it turns north to a central area in the Indian Ocean where it makes a three-point junction with one ridge that runs south of Australia and, finally, into the South Pacific, and another ridge that turns northwest toward the Red Sea. At the Red Sea the Rift proves its existence once more almost indisputably. At the southern mouth of the Red Sea, across from the Arabian port of Aden, one branch enters the African continent near the port of Djibouti in Italian Somaliland. The great crack in the earth forms the southern end of the Abyssinian Highlands, then turns south to form the Rift Valley of Eastern Africa. Water from the high mountains on either side collects in the deepest depressions of the valley to form some of the world's largest lakes, such as Tanganyika and Victoria Nyanza. Bordering the lakes are such volcanically formed peaks as Kilimanjaro and Mount Kenya. The other branch of the Rift in the Red Sea aims northwest and splits that, perhaps geologically very new, body of water neatly in half. (In passage the Rift seems to cause a unique mysterious type of sea bottom often called the "hot spot.") At the Gulf of Aqaba, area of contention between Israel and Egypt in their wars, the Rift leaves the Red Sea and turns north into Palestine where the depression creates the basin for the Dead Sea and the river bed for the Jordan.

Extending the Ridge into the Pacific, geophysicists

could not for long stretches find such obvious evidence of a rift. The Pacific does not lack ridges, or rises as they are more often called in that ocean, but many are far away from the well-traveled sea lanes and considerably less sounding work has been done there. Earthquake epicenters have been plotted, heat probes have been made, magnetism has been studied, but a globe-encircling rift does not show itself so clearly in this ocean. Some significance must lie in the fact that the Atlantic Rift has had three active volcanoes in the last decade while the Pacific area which may possibly contain the rift does not seem to have had any.

Yet Pacific rift phenomena are certainly not absent. Around Easter Island, on the large East Pacific Rise, a line of earthquake epicenters has been plotted and earthquake lines have also been plotted on two ridges, the Sala-Y-Gomez and the Nasca, that lead east from the Rise toward South America. Around the Galapagos Islands, Lamont-Doherty scientists have found definite symptoms of rift-type activity.

North of the Galapagos, Scripps Institution scientists have studied the Gulf of California with particular care. They have concluded that this long, narrow stretch of water between Mexico and the peninsula of Lower California is the result of sea-floor spreading from the crest of the East Pacific Rise. At the mouth of the Gulf of California, and the beginning of the continental shelf, the Rise ends abruptly. There is a pronounced fracture of the sea floor right at the mouth. Magnetic anomalies, the deviations from a regular pattern, occur here. The reversals have been dated from 3.4 to 3.7 million years ago. The Scripps inference is that Lower California has been rafted away from the Mexican mainland by spreading, within the last four million years. A fault valley runs up

the Gulf of California and comes upon the land near the mouth of the Colorado River. Continuing north it creates the basin for the Salton Sea and Death Valley, then perhaps continues on as the San Andreas Fault, major cause of California's earthquakes. North of San Francisco, the San Andreas enters the ocean, emerging once again to make its last appearance in Alaska.

Rift enthusiasts keep extending its range. Dr. Kenneth L. Cook of the University of Utah believes that another branch moves north from the end of the Gulf of California to create the great belt of trenches that runs through Arizona, Utah, Idaho, past Yellowstone Park in Wyoming (which might account for all the geysers), through western Montana and up to the Rocky Mountain Trench in British Columbia. In Utah this trench may be associated with the Wasatch Mountains west of Salt Lake City that are actively faulting at the present time.

Now, in Europe, an additional rift has been proposed. This would leave the Mediterranean at the mouth of the Rhone River, proceed north up its valley and that of the Saône River, cross over into the Rhine valley, continue into the North Sea and on up to Norway. It is true that the Rhine valley is widening slightly every year and that it has spread three miles in the last 40 million years. Many small earthquakes occur in the area and it is a region of hot springs. Once a grand idea, such as world-wide rifting, takes hold, no one can tell where it may go.

As mentioned, news of the rift revived the idea of continental drift. Obviously the rift is a very active zone, one that seems to be splitting apart. If the earth is splitting, expanding, here might be the answer to the question asked by Maurice Ewing in a chapter he wrote for a book titled *Ocean Science*. "How did all the low density material get to be collected in plates about 35

kilometers thick, covering only one third of the earth's surface? Why is it that the crustal material is not spread out uniformly? Furthermore, why have these plates collected almost entirely in one hemisphere?" If the earth has expanded to several times its former size, it may once have been covered by a single plate or crust that cracked under the strain into the pieces we now know as continents. This would, of course, also explain the origin and comparative youth of the oceans.

Here, then, is a return to the concept that one or two continents drifted apart. India, Australia, and the Antarctic moved away from the east coast of Africa, thus creating the Indian Ocean, while South America left Africa and North America separated from Europe, producing a new ocean to the west of the old mass that is now called the Atlantic. (What was going on in the Pacific during these events does not seem to be completely understood.)

As theory, drifting continents have had a fairly long history. Francis Bacon, one of the early philosophers of modern science, in 1620 noticed the remarkable fit between the coastlines of South America and Africa and suggested that these lands may have once been joined. A number of other men over the years thought and wrote about this idea. In the late nineteenth century Eduard Suess, an Austrian geologist, saw similarities in the geology of the lands in the southern hemisphere and placed them all together in one continent that he named Gondwanaland. The name came from an area of India that is geologically unusual. It has the only coal in India and most of the iron and manganese ores. Its fossils are very much like those found in Africa. Alfred Wegener of Germany early in the twentieth century prepared an elaborate study based on evidence from geology and pale-

ontology which he claimed showed that the earth once had just a single vast continent. He named it Pangaea. Wegener's theory generated a long and heated debate. It received much more acceptance in Europe than it did in the United States.

Now continental drift has become almost respectable, partly because of the new findings based on the magnetism of the earth. Almost everyone has probably played with a toy magnet horseshoe and seen it attract steel pins and pen points. Many people have also used a pocket compass. Magnetism relates intimately to various forms of iron, presumably because of the core of iron spinning inside the earth. It is certainly related to electricity, but no one can describe it or draw a picture of it.

Mysterious though it may be, magnetism has been used for some hundreds of years. Someone, often said to be a Chinese, discovered that a natural mineral, lodestone, if swinging freely on a pivot, always pointed north. A lodestone, the original basis for the compass, could be used by navigators at sea to help orient themselves while far out on the trackless ocean.

In time navigators, particularly those trying to find the Northwest Passage above Canada, learned that the North Magnetic Pole was not in exactly the same place as the geographic North Pole. When traveling in those cold waters they found that the needle would either whirl wildly or point to the true magnetic pole. This pole usually lies on Prince of Wales Island, some hundreds of miles away from the North Pole. Steering by the magnetic pole, in this area where it deviates so much from true north, could put a sailor in serious trouble. In the more usually traveled waters farther south, the compass pointed closer to true north, unless excited by some local devia-

tion caused by an abnormally high iron content in the bottom underneath.

The first suggestion that the magnetic poles had reversed their field came from a French physicist, Bernard Bruhus, in 1906. His reports did not create much excitement. Paleomagnetism only became an urgent subject in 1950 when geophysicists found consistent reversals in the various lava fields of Iceland (in terms of geology, a new volcanic island). Studies of the lavas showed that when the ages of the eruptions in various places were correlated, those which occurred at the same time had the same orientation to the magnetic poles' position at that moment.

That such magnetism is stable and does not change, once locked in, was proven by tests on Hawaiian lava flows whose recent dates were known exactly. Then, in 1958, when the method of dating ancient rocks by the different percentages of their potassium and argon content was developed, Australian scientists studied their old lava flows and calculated the dates of the reversals by radioactive rather than geological means. While confirming the dates by this independent method, the Australians also showed that the reversals were global, not just local.

The underlying element in the magnetism of rocks is, of course, iron. Lava flows contain a high percentage of iron. The lava comes out of its mysterious birthplace at a temperature of 1,000 or more degrees Centigrade. This red hot fluid melts whatever rocks it encounters, creating a new blend of material on the surface of the earth. When it cools through what is known as the Curie point, about 670 degrees, the iron in the amalgam becomes magnetized, lining up with the magnetic pole as it exists at that time. As has been said, this polarization is impervious to later change. The magnetized rock on a plain can become part of a high, folded mountain, in a process that may take

millions of years, but its polarization is constant. It is fossilized, frozen into position.

Magnetism is measured not only in continental rocks and in sediments brought up from the deeps but by magnetometers, towed behind surface ships and aircraft, which record the polarity of the magnetism on the ocean floor in that particular area. Magnetometers have demonstrated tremendous anomalies, or irregularities, running thousands of miles along the bottom of the Pacific. These are called fractures and the magnetism on the two sides of the fracture differs widely. The lines of magnetism will fit together, however, if lines as far apart as 600 miles are matched. This indicates that one side of the ocean floor has moved enormous distances away from the bottom that once lay right alongside. To visualize this, think of a ruled sheet of paper, cut in two, then shift the ruled lines, one up and one down, against each other. In the present state of the Pacific fractures, the ruled lines no longer run together. Magnetometer readings from various parts of the world have been correlated with each other and the dates of the various reversals have been found to be the same, no matter where the readings were taken.

Magnetic reversals now seem to be accepted by most scientists. They open up a whole Pandora's box of speculations, even including a possible relation to the fate of the dinosaurs. The reversals must surely bear some, though not necessarily causal, relation to the fact that the earth's climate has changed. To put it most simply, either the forces within the earth which create magnetism have changed their alignment with the surface, or the forces have remained constant and the surface of the earth has moved about.

The obvious changes in the earth's weather may be compatible with either thought. The coal and the verte-

brate fossil found in the Antarctic do require at some time a different temperature on that continent. The fossil, that of a fresh-water amphibian, could never have existed in the present climate of the Antarctic, nor does it seem likely that the animal would have swum across as much salt water as exists today between that continent and Africa or South America. (Numerous fossils similar to the Antarctic one have been found in both other continents.) The land at the bottom of the world today simply must have been warm at some time during the past. When? Well, the Labyrinthodonts, the family to which this fossil belonged, lived about 200 million years ago. This gives a somewhat fixed date for at least one temperate period but gives no idea as to when the land became cold. The fossil is one bit of a scientific puzzle to be fitted in with many others.

Those thinkers who maintain that the North and South Poles have always had the same geography under them, sea at one end and the present continent at the other, have tried to solve the changing climate problem by changing the angle of the earth's axis toward the sun. This would give the earth more of the sun's rays at some area other than our present equator. The change in tilt, once this hypothesis has been made, could easily put the land now presently at the South Pole in the latitude of the equator. Some geophysicists, however, say that a major change in the axis is impossible and cite the fact that all the planets except Uranus incline to about the same degree toward the sun and there is no evidence that conditions ever were different. (One might ask why Uranus deviates, but the question seems beyond the present scope.)

To explain the vast differences in the world's past weather some geophysicists have called upon the study named paleoclimatology, or ancient climates. According

to this branch of science, the continents cannot have always been where they are today.

Paleoclimatology assumes that the earth's rotation has always been in the same direction and that the axis is reasonably constant. If this is true, then the broad generalities of world weather must always have been quite similar to what they are today. The equator would always receive the greatest amount of the sun's heat. There would be six months of darkness at the poles during their winters.

The equator would be, as it is now, an area of low pressure with heavy rains. To the north and south, for about 30 degrees, the winds would blow fairly constantly from the east. The direction these trade winds blow is created by the earth's rotation, the Coriolis force, named after the nineteenth-century French scientist who first described what a turning world would do to the winds and water on its surface.

The next band to the north, from 30 to 35 degrees, would be the subtropical highs, the region of deserts in both northern and southern hemispheres. Next to the north, between 35 and 60 degrees, is the region of westerly winds, such as prevail in the United States where the weather most ofetn moves from the Pacific to the Atlantic. Farther north, a subpolar low-pressure area is found, then polar easterlies, and near the pole a high-pressure area. The same set of weather bands exist in the southern hemisphere. (These generalizations, of course, are modified by ocean currents, continental masses, and mountain ranges.)

While overseas as a graduate student at the Australian National University at Canberra, Neil Opdyke wrote a paper discussing paleoclimatology. In it he suggested where, from geological evidence, lands must have been in previous eras. From the hardened remains of ancient

sediments, which could only have developed in certain climates, from the evidence of wind-formed sand dunes that solidified in various areas, and from the magnetism of paleolithic rocks, he found the latitudes of Europe and North America much different in the past from what they are today.

Looking at the Permian remains in Europe, about 230 million years old, he located the continent mostly north of the equator but still definitely in the tropical zone. The area now known as northern Europe was in the desert belt that exists along the 30th parallel. (Today the deserts of western America, the Sahara, and the Arabian peninsula all lie roughly in this position.)

For North America during the Pennsylvanian age, 250 million years ago, Opdyke placed the equator diagonally across the continent, from Newfoundland to the Gulf of California. The major North American coal beds formed during this time, their major location giving the period its name.

Later, in the Triassic period, 205 million years ago, he described North America as 1,800 miles closer to the equator than it is today. This produced a tropical climate in Canada and left some coal in Virginia and North Carolina.

While such massive movements of continents may fascinate some geophysicists, in particular the younger ones, the idea has not yet received complete acceptance. For one thing, it seems to require such immense forces to move whole continents about that the sceptical find the whole thing impossible. Still, evidence from many different quarters continues to pile up. One possible confirmation comes from the study of red sandstone that has been carried out by Dr. S. K. Runcorn and Dr. P. M. Du Bois of Cambridge University in England. Dating

standstones of known, comparable age found in Great Britain and in Arizona, and demonstrating the differences in their magnetic polarity, Dr. Runcorn showed that North America and Britain must have moved 24 degrees apart in relation to each other since the time the magnetism of the sandstones froze about 205 million years ago. Dr. Du Bois found another, even greater relative shift in somewhat younger sandstones found in the two areas. No one claims that there has just been one, single drift of the continents.

Critics of continental drift ask for specifics about the source of energy that pushed such masses of land about. One of the explanations that met with considerable support came from F. A. Vening Meinesz. This geophysicist traveled in a Dutch submarine making gravity surveys over the deep-sea trenches and nearby island arcs of the Pacific. In these areas he found some of the greatest gravity deficiencies in the world. Or, as it might be put, a positive absence of mass. Some force was keeping these trenches down, prevailing against the earth's tendency to flatten itself out by filling in these deep gashes on its surface. Vening Meinesz reasoned that the process had something to do with heat convection, the transfer of heat by moving masses of matter. The convection current idea was later offered by the Dutch geophysicist to explain how continents may move. He believed that originally the earth consisted of just one kind of material. Radioactive heating caused a convection current to move within this single mass, which somewhat resembled a pan full of boiling oatmeal. As the material turned over, a slag-like layer of less density formed over the regions where the currents sank. This slag made up a single continental mass.

When instability caused by radioactive heating had

been corrected and the temperature was once more the same everywhere, a core of heavier material began to be attracted to the center by gravitational action. Once more the planet began to heat up. This time, because of the core, there were four convection cells. These dragged the continents into pieces, and each moved to a region of sinking currents. The Mid-Ocean Ridges are where the convection currents rise.

In the present decade both Harry Hess of Princeton, discoverer of the guyots in the Pacific, and Robert S. Dietz suggested that the Ridge and Rift were made of lava flows that welled up from the interior. As new material arrived through the Rift, the older material would be forced outwards from the center. As it moved over old sediments it would wipe them out. As the material from the Rift spread, it would serve to expand the earth and move the continents farther and farther away from one another. Dietz gave this process the name "sea-floor spreading." He estimates that the process began about 150 million years ago, went on actively for 50 million years, subsided, and then began once again about 30 million years ago. Dietz believes the rate of drift is between one to five centimeters a year. (This is based on the observed movement of California's San Andreas Fault.) In American-British terms this is something between one-half and two inches a year.

A quite recent theory, one that does not contradict other ideas now held about drift, is that the world crust is composed of a number of vast plates. These plates move about and sometimes override one another. A map of earthquakes prepared by Dr. Lynn Sykes of Lamont-Doherty claims to show that almost all the quakes occur in narrow zones that would be the margins of these proposed plates. The force moving these plates would, natu-

rally, be the magmatic material rising from inside the earth through the rifts in the ridges. As an example of this plate motion Dr. Sykes pointed out a series of earthquake records which indicate a movement of the central Pacific plate northwest in relation to North America and Asia. Such a motion would explain the earthquakes along the San Andreas Fault in California. Dr. Sykes concluded a report to newspapers by announcing, "We can almost say with certainty that continental drift is a reality."

The ideas of the new geophysicists seem very persuasive because they offer answers to so many questions, and all the thinking and research going on in the field suggest that there may soon be a unified theory that will explain many strange elements on our puzzling earth. We should know then why three billion years of sediment have disappeared, why only the last five percent of time is represented in the sea, and why the ocean islands and volcanoes are so geologically young.

A summary of the new geophysics, based on the ideas of continental drift and sea-floor spreading, might read something like this. The light continents are strong. The only thing, it seems, that can break them is material rising from underneath, as in the Mid-Ocean Ridges. After a fracture, the parts move away, as in the case of continental drift. If part of the ocean floor begins to sink, the continents move toward the area. Then a deep trench is formed that is bordered by volcanoes and chains of islands. The islands of the West Indies, Japan, and Indonesia all belong to such systems. When an ocean floor and a continent move together as if to collide, the ocean floor passes under the continent and begins to form a chain of mountains. These mountain chains are made up of the land itself, the continental shelf that has been pushed under it, and much of the sea floor as well. Vol-

canoes are formed under such conditions. The process is easily visualized on the west coast of South America. When continents collide with one another, as happened after the breakup of Gondwanaland, new mountain ranges also appear. Africa and India moved north toward Europe and Asia, pushing up the sediments of the ancient Tethys Sea (so that now there are fossil shells high in the mountains), and creating the mountain range that runs from the Atlas Mountains in Africa, through the Mediterranean to the Alps, the Caucasus, and the Himalayas.

If new mountain ranges are formed by continents being thrust over ocean floors, like the Andes and the very similar Sierra Nevada of California, if others are created by the collision of continents, such as the European-Himalaya chain of mountains, how can older mountain ranges be accounted for? Sir Edward Bullard, a witty English geophysicist with many discoveries to his credit, asked this question as he received the Vetlesen Prize for scientific excellence from Columbia University in 1968. He pronounced himself very dissatisfied with the Ural Mountains of Russia and the Rockies of North America. They had no right to be there. They lie much too far inland to satisfy present theories of mountain building. Sir Edward did not mention the Appalachians but they present the same problem. One answer has been offered. Perhaps these ancient inland ranges were formed long before the last time continents drifted. Perhaps the Rockies once were on North America's West Coast. Perhaps the Appalachians lay on the East Coast at a time when North America was plowing toward Europe. Maybe the Urals were erected when Europe and Asia came together in a great continental smash-up.

There should be little wonder that the new thoughts about the earth and its history are causing so much excite-

ment among the "ivory tower" scientists. The ideas are so dramatic and they make such vast events seem so simple. But, as Dr. Harris Stewart of the Coast and Geodetic Survey warns, "the sea floor spreading hypothesis cannot be used as the unique explanation for all major oceanic features." Nevertheless, many workers sense a major breakthrough in the near future when all the earth-shaping processes will be unified in one great theory. Then, someone will certainly ask, "Do the other planets behave like ours?"

VI.

The Ring of Fire

THE longest running show on record gives a performance every night in the Tyrrhenian Sea. Sundays and holidays included, the volcano Stromboli on an island off the coast of Italy has been erupting for at least as long as man has been writing down history. In the dark, the red glow from Stromboli's molten interior lights up the steam which rises incessantly from the crater, creating a spectacle that can be seen from many miles away. During World War II, Allied bombers used the volcano's beacon as a navigational checkpoint to and from their raids on the continent of Europe. Of all the volcanoes in the world, only Mauna Loa and Kilauea are anywhere near so consistently active. Stromboli presents such a spectacle that no one who has seen the gorgeous sight is ever likely to forget it. It seems strange, then, that the generic name for mountains that spit fire should come from the Latin word for the neighboring island, Monte Vulcano. Perhaps it is because Stromboli, for all its glorious color and hint of a writhing hell, is really not very violent. Vulcano, mythical home of the god of the forge, is not regular but, when it did erupt, it did so with a violence, a passion that must have seemed much more impressive to the ancients. Then, too, in the days when the Greek and Roman civilizations were

beginning to make records of what they observed, Vulcano was frequently, even if irregularly, active. It last blew its top in 1888, continued erupting until 1890, and has not been observed in action since then. Of course, like the nearby volcanoes, Vesuvius and Etna, it is not to be trusted. It might easily erupt at any time again. The question about this, as it is about all volcanoes, is "When will it happen?" The soil on the slopes of these mountains is so seductively fertile that men insistently live and farm there, even though they are perfectly aware of their peril. If science knew just why volcanoes select (it is difficult not to be anthropomorphic about such lively creations) the particular moment they choose to erupt, existing in such proximity to them might not be so dangerous. Some volcanoes do give advance notice of their intentions. The molten tourist attractions of Hawaii send warnings by a number of different signs that volcanologists have learned to recognize. One of these is increased activity in the magnetic field.

Yet a monitoring station located on the side of a suspicious volcano in the middle of Lake Taal, Philippine Islands, failed in its purpose. In July, 1965, the water temperature of the lake rose from 91 degrees to 113 degrees. The fact was publicly announced and a watch begun. Then the temperature dropped off somewhat. Suddenly on September 25, 1965, Taal exploded, killing 190 people and leaving the monitoring station under ten feet of debris. The resulting crater was a mile long and one-fifth of a mile wide. Taal erupted through what had just before been a rice field, bearing the best crop it had in years. The heat which must have been close underneath aided, rather than damaged, what it would soon destroy. Some of the most notorious volcanic explosions in history, Vesuvius, Krakatoa, Mont Pelée, have given

indications days in advance that unusual events were imminent. In no case do any of the nearby residents seem to have paid attention. Except in the vicinity of Mount Etna in Sicily, which erupts quite frequently and where the natives do not seem to get caught, people can live in the proximity of potentially violent volcanoes for whole lifetimes without ever seeing them in action. No one can exist forever in fear, so they become forgetful, unwary, philosophical. Great cities have grown up within sight of volcanoes; Naples and its Vesuvius, Tokyo and Fuji, Seattle with Mount Rainier, Portland and Mount Hood, Mexico with two volcanoes a short drive away. None of these seem to worry the citizens. With the exception of Vesuvius, they are all "dead." Though Hood and Rainier both exude steam and vapor at times, though nearby mountains St. Helens and Baker both erupted in the 1840s, although Mount Lassen, part of the same range, destroyed five million acres of timber in 1914 and 1915, people will doubtless always defy them. And, after all, volcanoes make the world's most beautiful mountains. On a clear evening from any high point in Portland, the sight of Mount Hood's snow-covered, perfect cone catching the last pink rays of the sunset is breathtaking. If the Japanese do really consider their Fujiyama sacred, one can well understand why.

A clue to the nature of volcanoes lies in the fact that they almost always occur in clusters. With some exceptions, they are near the ocean, very often on islands. Again with exceptions, such as Hawaii, volcanoes usually occur in the same places as earthquakes. The cause and effect relationship between eruptions and earth tremors is unclear. (There was a massive earthquake at New Madrid, Missouri, in 1811 and a minor quake at Philadelphia in 1968 but no volcanoes have been reported from either

community.) The safest generalization may be that most areas with volcanoes may also expect earthquakes but that earthquakes can occur very well without volcanism.

In certain areas of the world, the West Indies for one, but most notably in the Pacific, volcanoes bear some close relation to island arcs. To see island arcs, simply take a glance at a map of the world or a globe. Looking at the West Indies, start from Trinidad and look north up the Leeward and Windward Islands to Puerto Rico. The bits of land describe a graceful curve. In the Pacific the longest is the great sweep of the Aleutian Islands extending from Alaska more than 3,000 miles to Asia. The Kurile Islands, just to the south, are another arc, as are the islands of Japan and the Bonins, a little farther south, also called the Volcano Islands. The Marianas Islands make another arc as does the Philippines and the Indonesian chain.

In the South Pacific lie the arcs of the New Hebrides and Tonga Islands, and the arc from Timor to Sumatra. Could coincidence have made such similar curves? Might some explanation exist for the fact that all the island arcs have deep trenches off their shores, the deepest spots in the whole world ocean? The map shows how little of the earth's surface the island arcs occupy, yet they contain a great proportion of the world's volcanoes. When the world's total of about 600 active volcanoes are all marked out on a map, one quickly sees that at least two-thirds of them join in a circle around the edges of the Pacific Ocean. This is popularly called the "Ring of Fire." It includes not only the volcanoes of the island arcs but those of New Zealand, the Antarctic,* western South

* The claim has been made that the Antarctic does not have status enough to belong to the "Ring of Fire." It was supposed that only Mount Erebus and Deception Island were active, but two additional active volcanoes have recently been found.

America, Central America, Mexico, the extinct volcanoes of the United States, and the thirty-six that are active in Alaska.

Certainly no one can explain this global circle as an accident. Could the Pacific Ocean be compared to an enormous Catherine wheel that is slowly turning around a central axis? One proponent of this idea says that it takes about three billion years for the Pacific basin to turn a full circle. Whether or not such a fracturing motion sets free the fires of Hades around the rim of the Pacific, it does not quite explain the volcanoes along the Atlantic Rift nor the volcanoes that cluster around southern Italy. Nevertheless, a sort of comparison is possible. The Rift is certainly an area at least of earthquake motion, if not of spreading. Italy has many earthquakes, too, and its Apennine Mountains are rising while its Tyrrhenian Sea is sinking.

What do volcanologists actually know at the present time? The substances come from pockets of magma, pools between 20 and 40 miles beneath the earth's surface and perhaps 15 to 20 miles wide. These volcanic pockets can be measured because they do not transmit the impulses produced by seismic profiling that would be normal for this depth in the earth. The pools have only been found near or under proven volcanoes.

The source of a volcano's power is heat, though it remains to be settled if this heat is what remains at the earth's core from the time when the planet was one great molten mass, or if it is heat constantly being renewed as a byproduct of radioactive decay of deep rocks. Since probably no one will ever be able to settle this question at first hand (the heat barrier even ten miles down defies explorers of the most audacious science fiction) the answer will have to be provided by remote instruments.

Why do the pools of magma become unsettled and active? Apparently the pressure builds up, as it does in a cooker. The imprisoned gases and steam strain against the rock that contains them. As the pressure and the heat increase, the rocks melt and the safety plug is removed. (The first sign of this on the surface, as can be seen in Hawaii, is an upward bulge of the earth's surface.) The material bursts through the weak spot and a new eruption has begun.

Eruptions may consist of gas and steam, lava and pumice, or materials called pyroclasts: ash, dust, cinders, or slag. What comes out of the earth depends partly on the kind of rocks surrounding the magma pool but more importantly on the amount of pressure built up before the restraining forces gave way. The most dramatic, newsworthy volcanoes are called the explosive type. Within recent history, Krakatoa in the East Indies and Mont Pelée were explosive volcanoes.

In 1883, after several years of earthquake activity, the East Indies island, with three peaks and a height of 6,000 feet, almost disappeared from the earth. An explosion heard 3,000 miles away also generated, as the island collapsed, a monstrous seismic wave that killed 35,000 people living in seashore villages. The dust from Krakatoa darkened the sky all over the world, so much so that heat from the sun could not penetrate in the normal manner and temperatures everywhere were reduced an average of ten degrees for several years.

In 1902 Mont Pelée on Martinique, after several days of suggestive behavior, sent a "great cloud of incandescent gas and dust" into the city of St. Pierre and killed all but one of the city's 28,000 residents. Neither of these volcanoes produced any lava at the time of the explosion.

Contrasting these wonders of nature are the effusive

volcanoes, such as Mauna Loa and Kilauea in Hawaii. They do not blow their tops, but, with comparative gentleness, produce highly fluid lava that flows slowly over the land for many miles. Their craters are very broad and the crests on the rim quite low.

There is also an intermediate type of volcano, very explosive at times and at others capable of building very high, symmetrical cinder cones. Vesuvius is an intermediate, as are the volcanoes of Alaska and the old volcanic peaks in the western United States. One of the most beautiful, perfect volcanic cones in the world is Mount Pico in the Azores, which rises straight from the sea to a height of almost 10,000 feet. It is not far removed from the Mid-Atlantic Rift and a few years ago a small new volcano began life about a mile away, one that did not last long because it lacked the power to build itself above the forces of sea surface erosion. That Pico in its absolute symmetry is not world-famous must be due to the fact that it is off the main tourist tracks.

The word "volcano" is apt to produce an image in the mind of a mountain bubbling with fire. Some years ago there was a cycle of melodramas on the stage and in the movies in which the Polynesian virgin, always beautiful, was about to be sacrificed to the angry god of the local volcano (which was showing signs of erupting). The girl was always saved by the well-developed native boy, who had just grappled victoriously with an octopus or a man-eating clam, but it was the volcano that remained indelible long after the story was forgotten. Volcanoes, however, often come in other styles. Because of their prevalence there, volcanoes also produce what are known as Icelandic formations. Huge amounts of lava simply flow out onto a plateau without forming any mountain or cone at all. The flow may cover quite broad areas.

The Moon National Monument in Idaho, which covers 47,000 acres, has many small cones and craters but it has also some of the finest examples in the United States of areas covered by lava crusts. Similar areas in eastern Washington and Oregon covered by deep plateau lava have already been mentioned. Much of the world's surface must once have been covered in the same manner, but erosion and intrusive biological forms have obliterated many signs of such a past. Curiously, a large volcanic field of intrusive origin, lying between New Mexico and Mexico itself, remained undiscovered by geologists and map-makers until a satellite photograph found it in 1967.

Although their origins must be similar to those elsewhere on earth, the volcanoes of the Pacific have differences that make them worth separate discussion. Uncounted numbers of them, perhaps thousands, lie within the vast circle that rings the Pacific. These are all invisible to the sailor at sea. Another group, twenty strong, run in an almost straight line 1,600 miles long, right in the middle of nowhere. The very visible Hawaiian Islands seem vaguely similar to the Azores. Both are volcanic and in mid-sea. But the Azores are related to the Atlantic Ridge, and the Hawaiian Islands simply rise almost straight up from the ocean floor three miles and more below. They have practically no continental shelves. It almost seems as if the Pacific had generated an enormous fissure in its middle through which immense masses of lava flowed, building up until the surface had been reached in 20 distinct places. The active flow from the interior is still going on.

Most geologists think that the Hawaiian Islands began at the northwest end of the chain, at Midway Island, now one of the smallest. Lazy, effusive-type eruptions have been more or less continuous ever since the beginning of

the process, about 30 million years ago. As the chain developed in a fairly straight line from northwest to southeast, the islands increased in size until the largest, the island called Hawaii, was reached. It is the youngest and has the two active craters, Mauna Loa and Kilauea.

As they grew, the islands were subjected to many modifying forces. Corals built their reefs, the islands subsided at times due to their great weight, the sea level changed frequently, there were geological faultings and submarine landslides, but the unique Hawaiian Islands have persisted. And prospered, due to their estimable climate and their fertile volcanic soil. No one can yet say what caused the earth to split along this 1,600-mile line in the Central Pacific 30 million years ago. The surface of the earth has many other, even longer clefts, some even straighter, but no other cleft has produced anything comparable in the way of massive islands. (Though they look small on a world map, it must be remembered that each has a three-mile base of solid volcanic rock.)

How much different the "empty" North Pacific would look if several thousand other volcanoes, which tried to make it as islands, had not failed. The Pacific floor has still-uncounted thousands of volcanoes, called seamounts, that never rose above sea level. It also has as least 1,400 that once made it to the sun and then slipped back under the water. Why these failed while Hawaii was succeeding remains a debatable point. The fact is that the Pacific has lost more than 1,400 islands. The first of these casualties was only discovered during World War II.

Harry Hess, geologist from Princeton University, was aboard the Naval transport, U.S.S. *Cape Johnson,* while it served on war duty in the Pacific. The ship had an echo sounder that recorded the depth of the sea bottom. As the depth increased or decreased, the figure was marked

on a graph that showed the ups and downs, producing a picture such as you would get by drawing a line marking the peaks and valleys of a mountain range seen on the horizon. One day geologist Hess watched the recorder as it drew the profile of a large seamount. Being volcanic, the seamount should naturally peak with a cone. This time no volcanic cone appeared but the recorder did show a broad, flat top, at a depth of 800 fathoms (or 4,800 feet). A regular ship's officer observing this flatness would have thought nothing of it, perhaps because it held no menace for the ship's safety or maybe because he would not realize it was unusual. Such flat tops, it turned out later, must have been recorded many times but no one saw what was before his eyes until Hess pointed it out.

Alerted by his discovery Hess checked the shape of other seamounts as the ship traveled across Pacific waters. During his tour of duty he found nineteen other flat-topped, submerged volcanoes. Since they must have been originally conical, some force had to level them off, and the only power he could think of to do this was the erosive action of waves at the sea level. These features, however, never noticed before, were far below the waves, sometimes as much as a mile down. Realizing he had made a discovery, Hess named them guyots after Arnold Guyot who had been Princeton's first Professor of Geology in the 1860s.

Since Hess's discovery a great number of guyots have been discovered in the Pacific. The first dredgings of their tops produced fossils of shallow-water-type organisms dated as about 100 million years old, indicating the time when these mountains were last near the surface. Hess first explained the guyots as Pre-Cambrian (more than 500 million years old) peaks that had been planed off by the waves, then submerged as the sea floor sank due to

the heavy weight of sediment that had been accumulating since time began. It has since been shown, however, that the Pacific does not have enough sediment to account for subsidence to such depths, and in addition, shallow-water-type fossils have been found on some of the summits that are no more than 30 million years old. Though it has been suggested, to account for the leveling, that the sea level was once low enough, a mile less than it is today, to do the work, most scientists have found the idea difficult to take seriously. Subsidence seems the easiest answer to account for the downward motion of guyots; but if heavy sediments were not enough to sink the sea floor, what kind of action could have lowered such a great portion of the sea surface by as much as a mile? Very heavy lava flows in the distant past, as suggested by Dr. Roger Revelle, may have provided the enormous weight to accomplish the task. But why did Hawaii stay at the top?

Robert Dietz claims that guyots are not volcanoes that sank. He believes that they are older the farther they are away from the Mid-Ocean Ridge. Like the continents, they drifted away from the center and went below the waves where the water was deeper. This explanation seems more pertinent to the few guyots in the Atlantic than to the great number in the Pacific, since the Pacific has no rise anywhere near many guyots.

However, H. W. Menard of Scripps, in an article published in *Science,* December 9, 1960, wrote, "There is some evidence that the life of an oceanic rise may be rather short, and rises may be in different stages of development at the same time. All the ocean basins have median elevations except the Pacific, which, indeed, has a line of atolls and guyots (different types of deeply submerged former islands) rising from a series of narrow-steep-sided ridges. If a broad oceanic rise, faulted at the

crest and capped by volcanic islands, were to subside, the only evidence might be such a line of drowned former islands and linear ridges. The guyots of the central Pacific were islands roughly 100 million years ago, and if they mark a former rise, the period of its subsidence must have been quite short compared with the age of the earth."

Harry Hess's guyots have come a long way since he observed that first unusual seamount while aboard the *Cape Johnson.* They have become necessary parts of a grand idea that seeks to explain the lack of a central ridge in the Pacific, a lack that has disturbed the continental drifters ever since it was discovered. If the ridge once existed and then simply disappeared, leaving the guyots behind, several problems are neatly solved.

This is, however, not the end of extinct volcanoes. To look at photographs of those beautiful, palm-fringed reefs with their bright lagoons, one would never think the islands called atolls are the relics of old eruptions. Charles Darwin first had this idea while voyaging aboard the *Beagle.* He thought it would be a grand idea if some rich man financed the boring of a hole through the coral down to the rock that supports the reef. No rich man volunteered, but funds have been found for drillings that began in 1897. The first samplings brought up the remains of coral from 300 and more feet down, coral that can only live on or near the surface. This strongly suggested that the atoll had subsided. A drilling on Bikini in 1947 went down to 2,556 feet without finding anything but the remains of near-surface life. A hole in Eniwetok in 1952 finally found volcanic basalt at a depth of 4,158 feet. Darwin had theorized that living coral attached itself to volcanoes while they were still at the surface. In time the volcanoes slowly sank but not so rapidly that the coral could not keep pace by adding new material at or near

the surface, the only area where they could survive (thus keeping the memory of the old volcano alive, even though it might finally be as far as a mile below). The Darwin hypothesis, based mostly on reasoning about what had to be, is now verified by work in the field. At least two problems remain, however. Why did corals grow on the shores of some volcanoes and not others, the related guyots? Why, like the guyots, did the atoll volcanoes subside? A third question might also be added: Why are all these volcanoes in the central Pacific, seamounts, guyots, and atolls, now extinct and only the two on Hawaii still active? Why is this part of the Pacific so calm while its shores are so obviously restless?

In terms of the laws of nature, nothing can be said to be good or bad, but no human, face to face with an erupting, explosive volcano, would hesitate about which to call it. Still the slopes of volcanoes, once they have cooled, make fine vineyards. An excellent wine, for instance, called *Lacrima Christi* (Tears of Christ) comes from the vicinity of Vesuvius. And Italy gets the electricity to run her railroads from geothermal power, first cousin to volcanic power. Many areas of the earth, more often than not associated with volcanoes, are underlain by batholiths, masses of rock fairly near the surface, still cooling off from the time when they were buried deeper beneath the crust as part of the magma. These batholiths are the source of the geothermal power that heats Icelandic homes, produces Old Faithful and all the other geysers, provides the water for all the resorts around the world called Hot Springs, creates the warm pools where New Zealand's Maoris did their laundry, and in general, act quite benevolently. Why did batholiths rather than active volcanoes form in certain areas? Was the crust above more resistant or the pressure from below less insistent? Geo-

thermal areas might be considered the friendly relatives of volcanoes. Although they probably will never be of great importance to mankind in general, they are interesting symptoms of all the activity taking place beneath our usually unaware feet. Since they are readily accessible and comparatively safe, they might be used as gauges to answer the quite important question, Is the earth cooling off or heating up?

VII.

Some Curious Relations

PRESUMABLY all the features on the continents and in the seas belong to one grand design, if only we could see it. As of this writing, however, the master plan remains elusive. Knowledge of geology, since the invention of a word for the science about 200 years ago, has increased so that now whole libraries are filled with reports of observations made all over the globe. One might say, at the risk of criticism, that most of this material is descriptive rather than explanatory. It is easier to report that Mount Whitney is 14,495 feet high than it is to be sure why it, rather than another, is the highest peak in the United States south of Alaska. Names have been given to the major features of the earth's past, the Geologic Time Scale, and rocks or fossils from one time can be separated by the specialists from the remains of another ancient time. Many signs are known by which the Paleocene is seen to be different from the Miocene, or the Triassic from the Permian. The separations of these periods are known as "revolutions." The geologists know they happened. It remains to be understood why the revolutions happened, why the periods changed so much

that the differences can be recognized after 50 or 250 million years.

The reasons for small events are much more obvious than the reasons for large ones. It takes no perspicacity to see why the valleys of the Mississippi and the Missouri are littered with ox-bow lakes. The rivers have simply found a straighter course and left these old meanders behind. The great features of the earth, such as the many linear patterns on the ocean floor, do not yield their secrets so easily. What cause can be given for a 12,000-foot-high mountain range that runs for 2,600 miles in an absolutely straight line? Not only is this mountain range straight, the line runs almost due north and south. Since it is deep below sea level, the Ninetyeast Ridge in the not-too-well surveyed Indian Ocean was discovered only a few years ago. What could have happened within the earth to produce such a straight line? Whatever may have occurred must be related to volcanism rather than folding since folded mountains, such as the Rockies and Andes, do not seem to exist in the ocean. Could the lack of folded mountains in the sea be due to the supposedly expanding ocean floor? Could folded mountains only occur on continents that are in the process of contracting?

With respect to lines, the only true ones seen on a conventional map of the world are circles, the island arcs, mentioned previously in relation to volcanoes. All the arcs, with one large and one small exception, occur in the Pacific. They are all essentially the same, and so the West Indies, even though in the Atlantic, will be described in detail to explain the type, since more U.S. readers are likely to have first-hand knowledge of this nearby formation.

Technically, the feature should be called the Antilles island arc. It curves through the West Indies, separating

the Caribbean and the Gulf of Mexico from the Atlantic (having a major influence on large ocean currents in the process). Though seldom mentioned in the texts, it is interesting to note that the West Indies, like all but one of the Pacific arcs, lie at the western side of one of the two great oceans.

All island arcs are convex facing the sea. That is, the outside part of the circle is the one toward the open ocean. Each of these chains has a narrow, arcuate (bent like a bow), deep trench lying outside. The deep trench in the Atlantic, the Puerto Rico, is about 100 miles north of the Virgin Islands, Puerto Rico, and the eastern end of the Dominican Republic. The water in the Puerto Rico Trench is the deepest ever found in the Atlantic. A recording of 30,180 feet has been made. The walls of the trench are extremely sheer. The actual floor itself is very narrow and remarkably flat. Attempts to take dredge samples from the walls and floor have been made, but the problems of being essentially blind while maneuvering a balky instrument into a very small cleft have been such that little worthwhile material has ever been recovered. A French submersible, the *Archimede,* tried to penetrate the trench but found it extremely narrow.

Trenches commonly have a narrow strip parallel to them along the bottom that exhibits a very low specific gravity. The Caribbean has such a strip that runs all the way from eastern Cuba down to Trinidad. The volcanoes often associated with arcs and trenches commonly appear on the concave, or inside, of the arc, about 100 miles from the strip of low gravity, as is true here.

Antilles volcanoes, where they exist today, usually excite the interest of tourists. Mont Pelée on Martinique, cause of so much destruction in 1902, still exists, though almost always veiled in clouds. Three soufrières, the

French word for volcano, may also be seen. The one that dominates the island of St. Vincent's also exploded in 1902, killing more than 1,000 people. The island of Guadeloupe's soufrière, which emanates heat, also stands high above the landscape, usually enveloped in clouds. On the island of St. Lucia there is also a soufrière, now little more than a big field of steamy clumps of sulphur sufficiently hard enough to walk upon. St. Lucia shows clear evidence, however, of once having been volcanically more active. Outside the harbor of the little town of Soufrière there stand two sheer and handsome cones of basalt, at least 1,000 feet high, called Les Pitons. The eruptions which caused these unusual peaks must have been spectacular. Are they unique in the Caribbean or did others once exist?

Another arc of islands with an attendant trench appears in the Atlantic's South Sandwich Islands, on the same high, cold latitude as Cape Horn. The South Sandwich Islands appear to have all the classic features of this kind of formation; but they are so remote, and the trench so comparatively shallow, that not much study has been made of them. It would be interesting to know if this trench is juvenile, just beginning to form, or if it is an ancient scar now in the process of healing.

Only in a picture of what lies beneath the waves do the trenches of the Pacific show their importance. Their combined length, though they have not all been completely surveyed, must total more than 20,000 miles. With two exceptions, deep trenches lie between every major Pacific land mass and the deep sea. The exceptions are the west coasts of the United States and Canada, and even though they have no trenches, there seems a hint of them in the fact that neither of these coasts has any appreciable continental shelf. There also seems a hint of something

else in this lack of trenches on the Pacific side of the United States and Canada. If North America is crashing west over the ocean floor, trenches that once existed may have been smothered. In any case, the two nations should not complain over their lack of uniformity with the remaining Pacific coasts. Trenches are the world's greatest breeders of earthquakes and seismic sea waves.

The trenches on the American side of the Pacific have no island arcs. The ones along Mexico, Central America, and South America are only slightly deeper than the trench north of Puerto Rico. While the bottoms of trenches are usually as flat as the abyssal plains, those off Chile and Peru have a V-shape, like a folded piece of paper. On the seaward side, the fold is very thin, like the ocean bottom, while the fold on the side toward land is as thick as the continental shelf. While the basic cause of trenches in the deep sea may be the same everywhere, as suggested by the many characteristics they have in common, they must at least be of different ages to account for the differences.

The depth of many of the trenches off the islands bordering Asia are remarkably similar. The difference in soundings between the Tonga and Marianas Trench, at present, is not much more than a hundred feet. Biological surveys of these deeps by Dr. Anton Bruun during the *Galathea* Expedition conducted by the Danes between 1950 and 1952 showed that animal specimens from one trench differed hardly at all from creatures recovered from another. All of them, however, differed remarkably in their adaptation from animals of the same type that lived in shallower water. Bruun reasoned that the trenches might be in a continuous state of motion, opening at one end, closing at the other, so that creatures who could only live at five to seven miles of pressure could survive by

moving to a new area of trench as an older one folded shut behind them. In any case, the closeness of the various depths suggests very strongly that whatever force is molding one western Pacific trench is working with equal force on the others.

While the existence of these trenches has been known for some time, surveying them all in such a vast expanse of water required many expeditions and increasingly accurate equipment. For some time it seemed that the Mindanao Trench off the Philippines was the deepest, with 30,100 feet. Then the Tonga Trench took over with 35,640 feet. A little later the British ship *Challenger II* reported nearly 36,000 feet from the Marianas Islands. The Russian oceanographic vessel *Vityaz* then investigated this claim, finding a spot they measured as 35,056. The Marianas Trench (or Challenger Deep) has kept its lead since that time.

The men on the *Vityaz* tried to lower a dredge three times down into this crevasse to sample life on the bottom but were hampered by strong winds which kept moving the ship from its position and by the fact that the crack was only one mile wide. To see the problem, imagine yourself in an airplane on a pitch-black night, seven miles above the earth, buffeted by winds, trying to lower a line completely invisible to you, through layers of air currents, on to a stream no wider than the Potomac at Washington. Though frustrated at this attempt, the *Vityaz* did go on to successfully dredge living forms from the Kermadec Deep and the Kurile Trench and find a new trench north of the New Hebrides Islands.

True exploration of the Marianas Trench required another sort of instrument. This turned out to be the bathyscaph *Trieste* invented by the Swiss professor, Auguste Piccard, who had made his initial fame balloon-

ing into the stratosphere. Later Piccard became fascinated with the problems and prospects of going down in the deep sea. Using the shape of a sphere, the structure best suited to withstand the pressures of the water environment, he designed and built a number of models before the *Trieste*. When the U.S. Navy bought the vessel from Piccard and transported it to the Pacific for research work, they invited Piccard's son, Jacques, to come along as technical adviser. After a number of preliminary tests, the *Trieste* was ready for the big, though still secret, experiment off Guam in the Marianas Islands on January 23, 1960.

In the annals of human daring, this descent to the bottom of the sea, the deepest point on earth, under seven miles of water in the blackest of nights, with water only a few degrees above freezing, far beyond any hope of rescue, is recognized as a very important first. (And last, too, since unless someone digs a deeper hole, there is no place farther beneath the sky for anyone to explore.)

Jacques Piccard and Lieutenant Don Walsh of the U.S. Navy were assigned to make the record journey. After towing the bathyscaph 200 miles from Guam (the *Trieste* could only travel vertically), the carefully planned event was delayed for several days by bad weather. Excerpts from Piccard's own account give some of the atmosphere and the story.*

All through that stormy night [before the dive] the team of scientists aboard the destroyer escort sought to pinpoint that deepest hole with TNT charges. They were still making explosive soundings when I went on deck in the predawn of Dive Day. A shuddering KER-UMP signaled the eight hundredth attempt to sound that big hole.

* Jacques Piccard and Robert S. Dietz, *Seven Miles Down* (Longmans, Green, 1961).

The descent was originally scheduled for 0700. With the bad weather it was dangerous to board before daylight. So I set it for 0800.

I asked myself . . . Was it sheer madness to dive seven miles into the sea under such conditions? I looked across the angry seas and saw that Walsh was having a rough time getting seaborne from the *Lewis* [the destroyer escort] in a motor whaleboat.

Walsh leaped aboard in good Navy style. Then he looked things over. He didn't like what he saw any better than I. He shook his head. "What do you think, Jacques?"

It was now 0800. The time factor was critical. If we were going to dive that day, we couldn't delay much longer. It was vital to accomplish the 14-mile round trip to the ocean floor and back before darkness. If we didn't surface until after dark we might not be spotted. It is all very well for a man seeking adventure to take chances. I wasn't looking for adventure. I wanted a successful and uneventful operation. I wanted to leave nothing to chance. I made the decision. We would dive.

Through the after porthole I could see water flooding the antechamber. Suddenly, at 0823, the rocking ceased, the sphere became calm. I glanced at the depth gauge. The needle was quivering. We were on our way down. I looked over at Walsh. We both sighed in relief.

As we plummeted, there was an illusion of great speed. And we *were* falling fast more than three feet per second (the speed of an average elevator). Now, Walsh made telephone contact with the *Lewis*. This tenuous connection with the surface world is a pleasant diversion. Why, I don't know. We were now far beyond the reach of assistance.

My plan was to plummet the first 26,000 feet. Then I would reduce speed. I recalled a very real hazard. The charts had warned me that the bottom of the cleft into which we were plunging was a scant one mile in width.

0920—Depth 2,400 feet. Outside, total darkness. We brought out our first chocolate bars—the only food aboard. 0937—5,750

feet. We continued to plunge. Black water rushed upwards past us. Successsively, we overpassed the record depths we had reached on preceding [test] weeks. 1130—27,000 feet, right on schedule.

1144—29,150 feet. Now we are as deep under the sea as Mt. Everest is high above it.

1200—31,000 feet. Trying moments were ahead. We were venturing beyond the tested capabilities of the *Trieste*. I peered out the window looking for bottom—and then back to the echo sounder. But there is only water and more water. Then, an uneasy thought. What would the bottom be like? Clearly, we were in the axis of the trench. Dietz who was aboard the *Lewis* had advised me that there was an outside chance that the bottom sediment would be a flocculent and unconsolidated "soup" of recently deposited turbidity current beds. Could we sink and disappear in this material?

1206—32,400 feet. A strong, muffled explosion! We waited for something to happen. Nothing did. "Have we touched bottom?" Walsh asked. "I do not believe so," I replied.

36,000 feet, descending smoothly at 60 feet per minute. Now we are at the supposed depth of the Challenger Deep. Had we found a new hole or was our depth gauge in error. Then a wry thought—perhaps we'd missed the bottom!

1256—Walsh's eyes were glued to the echo sounder. I was watching alternately through the port and at the fathometer. Suddenly, we saw black echoes on the graph. "There it is, Jacques. It looks like we have found it!" Yes, we had finally found it, just 42 fathoms down.

While I peered through the port preparing to touch-down, Walsh called off the soundings. "Six fathoms—we're slowing up, very slowly, we may come to a stop. You say you saw a small animal, possibly a red shrimp about one inch long? Wonderful, wonderful! Three fathoms—you can see the bottom through the port? Good—we've made it!"

The bottom appeared light and clear, a waste of snuff-colored ooze. Indifferent to the nearly 200,000 tons of pressure clamped on her metal sphere, the *Trieste* balanced herself

delicately on the few pounds of guide rope that [now] lay on the bottom, making token claim, in the name of science and humanity, to the ultimate depths of all our oceans—the Challenger Deep. The depth gauge read 6,300 fathoms—37,800 feet. The time—1306 hours.

Later, a Navy laboratory and several oceanographers applied corrections to the depth gauge for salinity, compressibility, temperature, and gravity and came up with an official depth of 35,800 feet, or 5,966 fathoms. Since this figure agreed with soundings taken by American, British, and Russian ships, there is no doubt that the *Trieste* reached the deepest hole in the trench.

The achievement of the men who conceived, built, and manned the *Trieste,* striking as it is, still leaves the basic mystery unsolved. Now men have been down in the trenches. They have been proven to exist, not just by soulless instruments, but by the best instrument of all, man himself. What causes the trenches? Why are there volcanoes and island arcs nearby? Why do the trenches off the western Americas lack the island arcs? Why is the gravity so deficient in the trenches? Why (and these facts have not been mentioned previously) is the earth's mantle under the trenches so much thicker than under the sea bottom in general, and why, particularly at depths so much nearer the source of heat, is there such a slight heat flow from the trench floor as compared with other parts of the ocean? What prevents the mass of material on the trench walls from simply moving in and closing up the cavity? The earth, it is said, naturally tries to balance everything and keep it all on the same level. A final answer to all this would be a gigantic step toward a unified theory of the earth itself.

Geophysicists have reached some agreement on what

happens in the trenches. Great lines of the oceans' crust are folding down, buckling into the trenches. The trenches keep absorbing this material, as well as sediments from the land side, and somehow suck it down and under. In terms of human time, the motion is imperceptible but nevertheless seems definitely to be going on. The island arcs are explained, as are the mountains on the west coast of the Americas, as the material that has been pushed down, or pulled down, into the trench, then forced to the continental side of the trench. Surface material must rise under the pressure of the mass coming underneath it. The material being forced up is the substance of the island arcs and probably, at least in the case of the Andes, the basement for growing mountains. All this subterranean activity upsets the earth's mantle, loosening the crust that keeps the magma in check and creating the conditions suitable for volcanic eruptions. This same activity, of course, causes great blocks of earth to move creating the phenomena known as earthquakes. The islands form arcs parallel to the trenches because the basement material moves under them in this shape. Why are the trenches curved? Because, although actually straight lines, they must follow the curvature of the earth. What made the cleavages known as trenches in the first place? Perhaps this can be answered by asking, first, where the mass of material comes from that goes into the trenches. One theory is that of convection currents which move the ocean surface away from the mid-ocean ridges toward the continents. When all of this substance reaches the resistant continental blocks, the collision forces much of it downward and much of it upward into new islands and mountains. (An objection might be raised that the Pacific, where most of the trenches are today, seems de-

ficient in mid-ocean ridges but perhaps convection may operate without them.)

The Pacific island arc, volcano, and trench system seems to be geologically youthful. The Aleutian Trench, for instance, is dated somewhere between 10 and 50 million years old. Maurice Ewing reports that a trench filled with sedimentary rocks has been found to border the continental slope off New England. Possibly, at one time, trenches marked the boundaries between all continents and oceans.

Theories are relatively easy to produce. Facts needed to satisfy the critics are much more difficult to acquire. Yet, in the case of the Pacific, facts may be coming in too rapidly. Whoever explains the island arc system satisfactorily will have to fit it all together with the great Pacific fractures now being discovered.

In recent years another major group of mysterious features has been discovered off the western coasts of the Americas. One of these is a gash at least a mile deep that runs for thousands of miles across the Pacific floor. Another deep gash seems to run across the entire Pacific basin, about 8,000 miles, one-fourth the distance around the world. Eight such "great" fractures are known at present. All run in a general east to west direction. The name "great" has been given them to distinguish these gashes from a number of smaller ones now in the process of being charted.

The large fractures were discovered by detection of their magnetism, which is not what it should be. The lines of magnetism in the eastern Pacific run north and south, conforming to the general position of the magnetic pole. At eight positions, however, ships towing magnetometers have found very definite breaks in the proper north-south magnetic line. At these breaks, or fractures,

the line is displaced very considerably east and west. At one of the larger of the fractures the displacement amounts to about 600 miles. The ocean floor south of the fracture lines up magnetically with that north of the fracture only if the two blocks of crust, on a diagram, are shifted a total of 600 miles toward one another. Some tremendous power has pushed great blocks of the earth that far away from the land next to it at some time after the magnetism became frozen.

In general the trend of the fractures is east-west, much like the lines of the earth's latitude. The lines are not so perfect as one could draw with a ruler but they do follow the great circle course, the curving course a ship makes on a conventional map with its Mercator projection, in practice making a straight line on the world's curving surface.

The fracture farthest north is the Chinook, actually several deep gashes not too far south of the Aleutian Islands. The Chinook conforms least to the general pattern of the fractures. Next south is the Mendocino, the one whose north and south sides have slipped 600 miles in relation to each other. The feature begins off Cape Mendocino, the most westerly point in California, somewhat north of San Francisco. (The San Andreas Fault enters the ocean at Cape Mendocino.) For the first 1,000 miles out to sea the Mendocino is a great mountain range with very steep sides. At the coast the range is only four miles wide but has spread to a width of 100 miles when the deep, one-mile chasm begins. The mountainous area has such swarms of seaquakes along a small rift valley that some workers believe it is a fracture zone in the process of being born. The true fracture area has cliffs from 6,000 to 9,000 feet high. The Mendocino Fracture has not been surveyed for its entire length; including several branches

at its far eastern end, it must extend for at least six or seven thousand miles.

For some reason not yet well explained, the fractures down the east coast of the Pacific are remarkably evenly spaced. The Murray Fracture begins off Southern California and reaches out at least as far as the Hawaiian Islands. The Molokai Fracture moves out from a point off Baja California, under the Hawaiian island of that name, and is discovered again west of the island in a somewhat splintered condition. Next south is the Clarion; then the Clipperton, perhaps the longest of all; the Galapagos; and then the Marquesas at 10 degrees south of the equator. Some of the fractures may extend under the continental masses of the Americas but this is not yet certain. The connection that seems most proved at the moment is that of the Clarion Fracture with the volcanoes of southern Mexico and the island of San Benedicto, off Mexico, which had a volcanic eruption in 1952.

These fractures pose large problems for the geophysicists. They are not the only fractures in the world; but they are the longest and straightest, and are distinguished by the even spacing between them. They must bear some relation to the East Pacific Rise, the long, low range that extends 13,000 miles from south of New Zealand to the entrance to the Gulf of California. The rise resembles the Mid-Atlantic Ridge in some ways, but has no great rift system. The East Pacific Rise has small fractures at right angles to its course that begin south of the first great fracture, the Marquesas. The Marquesas, Galapagos, Clipperton, and Clarion Fractures all begin on or near the summit of the Rise. The Clipperton, Clarion, and Molokai all run straight for an average of 2,800 miles to the east, then branch in several directions. Although volcanoes can be found everywhere in the Pacific, the largest

ones occur west of the branches of the fractures. The Molokai Fracture has some relation to the Hawaiian volcanoes but the fracture is evidently older because the volcanoes are built over it and bury it.

Among the questions raised by all this are, What caused the Rise originally? Does it extend under western North America? No satisfactory answers have been given for the origin of the Rise, but it certainly must have something to do with similar features in other oceans. There is reason to believe that it does extend under North America. It stops abruptly at the mouth of the Gulf of California and then reappears in the sea once more off the coasts of Oregon and Washington. In some way, the Rise and the hypothetical Rift in the Pacific seem to follow the same course. This Rise does not cause the earth to bulge in the western part of the United States as it does in the sea, but many geologists firmly believe it is there. It is very difficult to trace such features on land since erosion and mountain building have altered them so much. There is no particular evidence of magnetic anomalies where the Rise might run through the United States. Theorists about the fractures have not been able to reconcile them with the San Andreas Fault, which certainly lies in the same area, even though at right angles to the fractures. Perhaps the San Andreas Fault occurred at a later time and has no immediate relation.

Writing in *Science* on January 6, 1967, H. W. Menard of Scripps stated, "The origin and history of these great fracture zones are not becoming more obvious as additional facts accumulate." Menard finds the probability of a relation between the fractures and the Rise increased by the discovery that all the fractures began to branch at about the same distance from the crest of the Rise. He also sees other possibilities, however. The fracture zones

of the central Pacific may not be branches of the large fractures coming off the Americas but a separate system that merely intersected. Menard thinks that possibly the whole pattern of fractures goes very far back in the earth's history but can only be seen in the Pacific because, at this point in time, the forces that cause it are only operating in the Pacific area. He finds the length of the Clipperton Fracture so remarkable (a circle that runs one-quarter of the way around the earth) that he cannot believe it was produced by anything less than some kind of global movement.

The great Pacific fractures do offer a number of puzzles. On a simple level one might ask where all the material went that was pushed as much as 600 miles, in the Mendocino, from its original position. Six hundred miles of ocean crust, forced against an already existing bottom, should have forced something upward and created some kind of folded mountains. No such mountains exist, nor is there any evidence of a downward fold into the mantle. The cracks just stop. What happened to all the crust that has been displaced? It does seem that an explanation of the fractures will have to take that into account.

VIII.

Why Does the Earth Quake?

FOR our peace of mind, it seems good that our imperfect senses do not tell us that our solid earth trembles almost constantly. Every few minutes, somewhere on earth, part of its crust moves sideways, up, or down, but we cannot see these events, nor feel them, nor hear them. Recordable quivers occur more than 10,000 times every year, but we only know this by instruments.

We remain happily unaware of the countless little seizures, but the big ones strike terror. In between, there are degrees of earthquakes less than dangerous but quite noticeable enough to cause lively conversation. A relative scale was devised by Charles Richter of the California Institute of Technology in 1956 so you may know just how much earthquake you are enduring. The degrees of intensity go from 1 to 12. (Below 1 the tremor can only be detected by seismographs.)

Number 1 on the Richter scale can be felt by very few people. Number 2 is apparent to people at rest on upper floors. A number 3 earthquake makes people indoors aware something is happening. Hanging objects swing. During 4 hanging objects swing more noticeably. Vibrations are felt such as those caused by heavy trucks. Windows, dishes,

and doors rattle. Glasses clink. Some houses begin to creak. Number 5 on the Richter scale can be felt outdoors. Little objects fall over. Doors move, open and close. Pendulum clocks behave erratically. Number 6 earthquakes make themselves heard. People run outside. Glasses, dishes, and windows break. Books fall out of bookshelves and pictures fall from the walls. Furniture moves or topples over. Plaster walls begin to crack. Small bells in steeples begin to ring. Trees and bushes shake. During a scale 7 earthquake it is difficult to stand. Weak chimneys tumble. Loose bricks, tile roofs, architectural ornaments shake loose. Large bells ring. At 8 it becomes very difficult to steer an automobile. Ordinary masonry collapses. The best built masonry resists. By 9 on the scale there is probably panic. Many buildings crumble or at least move from their foundations. Reservoirs are endangered. Pipes underground are destroyed. Large cracks are seen in the ground. The worst modern earthquakes have not registered beyond 9 on the Richter scale, but it is interesting to note that at 12 the damage is nearly total. The scenery is moved about very significantly. Things are even thrown into the air.

This list describes what happens due to the direct effect of the tremors. It does not give any figures for the amount of energy involved, nor does it describe the side effects, usually the worst part of such an event.

Domestic fires left untended while people run outdoors for safety are one great source of disaster, particularly in communities that heat and cook with coal or wood. A stove or fireplace may tumble over, spreading fires that will ignite anything that will burn. Lumber yards, fuel storage tanks, natural gas tanks are also good sources of fire. In the general disruption, with water mains frequently broken, fire fighting becomes extremely

difficult; and a conflagration may easily get out of control.

Towns in valleys below dams may be flooded if the dams burst. Landslides may block river valleys, forming natural dams through which rivers may burst in torrents at some later time. Communications with the outside world, highways, bridges, railroads, telephones, and cables, may be seriously disrupted, hampering relief work. Inactive volcanoes may be set off by the earthquake forces. Landslides may also wipe out whole sections of a town or waterfront.

Communities by the sea face an additional hazard. An earthquake may cause the water to recede so that wide areas of the ocean, or often a river floor, are exposed. Then the water may come rushing back in tides many feet above normal, sending waves crashing into inhabitated areas, destroying buildings and killing many unwary people. Many earthquakes on the edge of the sea also cause other enormous waves that travel at speeds of 500 miles per hour, and even more, for thousands of miles. Such waves, most usually in the Pacific, have arrived without warning at seacoast towns as much as 10,000 miles away, killing hundreds of people and destroying property under crests of water that may rise as much as 50 feet above the average.

Nothing in the English language suggests anything more vast than the phrase "earthshaking." What else could the person who first said it have been describing except the awesome effects created when two parts of the global crust move suddenly against one another?

Massive quakes must have occurred throughout the earth's past. Most of the faults on land along which they happened have been obliterated by erosion, covered by sediment, or hidden by the folding of new mountains over them. Early historical records of massive shocks exist only

when they took place in populated areas. Evidence is slim, but it seems likely that the Minoan civilization of Crete was destroyed by a massive shock about 1500 B.C. Records are better for an earthquake in A.D. 7 at Hsien, China, where hundreds of thousands were killed. The list of major earthquakes prepared by the U. S. Coast and Geodetic Survey begins with Chihli, China, in 1057 when an estimated 25,000 inhabitants died. The Survey lists a total of 47 important quake disasters since that time, with the record casualty list that of Shensi, China, on January 24, 1556, when 830,000 people lost their lives. Calcutta in India on October 11, 1737, produced the second highest estimated total in history, more than 300,000 dead. A figure quoted in a number of books gives the known dead from earthquakes since the birth of Christ as over three million souls.

The earthquake that severely shocked Europe and caused one of the world's funniest novels to be written happened in Lisbon, Portugal, on All Saint's Day in 1755. There was nothing amusing about the disaster, but it inspired the sardonic Voltaire to write his classic *Candide,* a satire on the then-current popular philosophy that "this is the best of all possible worlds." In the light of Lisbon's destruction, and with a further catalog of contemporary horrors, Voltaire asked how anyone could believe such nonsense. He was no less concerned over the fate of the lovely city than anyone else in Europe, but he believed that the melancholy event was due to natural causes and not to be blamed on an angry God punishing the Portuguese for their sins.

Lisbon lies on the wide, tidal Tagus River, only six miles from the open Atlantic. It had 32 churches, most of them full of devout citizens celebrating the special services when the first vibrations began. Stonework began

to crack as more shock waves followed the first one. Altar candles were knocked over and began to fire woodwork and clothes. Cooking fires in homes contributed to the blaze. People ran into the streets. More massive trembles came from the earth. A crowd rushed down for safety to a new stone dock on the river bank. It crumbled, throwing hundreds into the river. Uncontrollable fires continued to spread throughout the city.

The river Tagus receded to the ocean, leaving its channel bare, then returned with enormous waves that crashed as far as half a mile into the stricken city.

Seismic waves were soon felt in England and, before the day had ended, in the West Indies. Sympathetic earthquakes, or apparently that is what they were, happened within a few hours in North Africa. High waves were generated on many European lakes. The Lisbon earthquake caused comment for many years, but, in 1755, scientific thought had not quite yet reached the point where men were able to assign any rational cause to it.

Certain areas of the world are particularly susceptible to earthquakes, but evidently no place on earth is immune to them. No one thinks of the Mississippi River valley as a great seismic center, but one of the strongest shocks in U.S. history happened there in 1811. That the event is not as famous as others is due to the fact that the valley was sparsely populated at that time. The convulsions began near the small town of New Madrid, Missouri, in the early morning of December 16, 1811. Most of the wooden, frame houses in the community, population 1,000, were destroyed immediately. Thousands of acres of river bottomland sank 10 to 15 feet. Tremors were felt as far away as Boston; and in Charleston, South Carolina, a steeple swayed so much from the motion that its church

bells rang. The shocks continued until March of the following year. An amateur scientist in Louisville, Kentucky, counted about 2,000 of them. Another quake struck this same unlikely area as recently as November 10, 1968. It was felt in twenty-two states but centered in southern Illinois, about one hundred twenty miles east of St. Louis. It registered 5.5 on the Richter scale. According to the Reverend Donald Roll, a seismologist at Loyola University in Chicago, it will be a long time before the next one. "That was a kind of safety valve. The pressure which had built up has been released." He added that the quake might have been caused by the millions of tons of silt that flow out every year from the Mississippi into the Gulf of Mexico. "It's quite possible that the tons of silt triggered a see-saw effect on the vast continental blocks beneath the earth's crust. The weight of the silt depressed one end of the block and tipped up the other."

The most famous earthquake in U.S. history is undoubtedly the one that almost led to the destruction of San Francisco. It began early on the morning of April 18, 1906, while the citizens were still in their beds. Hundreds of buildings were damaged, some collapsed, but the major damage was done by fire. Since the water mains were broken, the flames raged unchecked. Finally, many houses were dynamited to clear an area as a firebreak. Several hundred people were killed by collapsing buildings during the initial shock and many others died of disease in the emergency camps set up for the homeless. Four square miles of buildings in the center of the once proud city were destroyed, and the damage was estimated at $400 million. Two nearby mountains moved ten feet apart from each other.

The villain in the case of San Francisco stands convicted as the San Andreas Fault. A fault is a great fracture in the

crust of the earth along which movement has taken place. The fracture called San Andreas, which runs north and south more or less parallel with the California coast, has been measured for a length of at least 600 miles. As mentioned, it begins at the northern end of the Gulf of California and continues until it enters the sea near Cape Mendocino, north of San Francisco. The fault seems to have some connection with the Mendocino Fracture, which begins here with the Gorda Escarpment; but the details of the relationship are still not certain. In any case, a large displacement occurred on the Gorda Escarpment in 1906, the year of San Francisco's disaster. The age of the fault is not known but probably amounts to millions of years. It is known that the fracture is 30 miles deep, that the land on the west side always moves northwards relative to the east side, and that the two sides have been displaced against each other by at least 300 miles since the movement began. The line can actually be seen at many places on the California landscape. The fault is most visible on the cement floor of a winery in Hollister, California. The building was constructed without the owners knowing that the San Andreas Fault lay right underneath. Now the floor is splitting apart at the rate of one inch per year, a movement that will eventually destroy the winery.

The event of 1906 did not mark the first time that the San Andreas Fault took a sudden jump. Observers recorded four such events in the nineteenth century, the most severe being that of 1857. This 1857 earthquake was probably the strongest to happen in the West since white men began to settle there, but not such a great disaster since the population was still small. Of some significance is the fact that the San Andreas Fault near Los Angeles moved markedly in 1857 but has remained locked in

position since that time. A fault that slips a foot or so in position every year is giving under a strain. A section of fault that does not slip, but remains locked in position, is being subjected to forces that may cause it to give way very suddenly.

A 130-mile area mid way between Los Angeles and San Francisco is the scene of the present slipping of the fault. From 70 miles south of San Francisco, through the city, and to the north, the fault has been locked in position since 1906. The situation very strongly suggests that the motionless section is undergoing strain. That the fault near San Francisco and near Los Angeles has not moved recently is shown by the fact that old fences have remained in the same position since each of these two regions, respectively, had their last large quakes. In the central active region, fences, sidewalks, and streets in the town of Hollister are regularly being displaced. The painted white center line at one point on California's Highway 46, overlying the fault, moved five inches out of position in 1966.

Recently a number of different kinds of instruments have been set up along the fracture to gauge its motion. Deep holes down to 10,000 feet (earthquakes in this area originate at 15,000 feet) are instrumented to register tremors, note any tilt in the rocks and measure changes in strain. On the surface conventional surveying methods are used periodically to measure any changes in the relation of known landmarks. These and other tools may make it possible to determine the breaking point before it happens. Whether the residents of California's two greatest metropolitan areas can benefit from early warnings remains to be seen. If everyone in that land of automobiles got in their cars at the same time to flee the holo-

caust, they would probably cause the world's ultimate traffic jam.

Thoughts on the prevention of earthquakes have included the idea of forcing vast amounts of water into the fault to lubricate it, and the notion of exploding atomic bombs to relieve the strain before it becomes too great. The advocates of these measures have not calculated all the side-effects of great amounts of water, massive explosions, or radiation on the environment. Prevention will doubtless remain a very distant goal until scientists have a better understanding of earthquakes. Meanwhile, the careful study of the special California situation does point up two basic questions needing solution. What is the exact pressure point when the strain becomes too much and the fault suddenly slips again? What is the relentless pressure in the earth that causes one great mass at least 600 miles long to scrape constantly against the land alongside, and why has this probably been going on for millions of years?

California today, of course, does not live alone with a perpetual earthquake menace. Even more volatile parts of the earth exist. Since 1962 about twenty-seven thousand people have been killed during seven earthquakes in the Asia Minor countries of Turkey and Iran. Records show that during the past millennium hundreds of thousands more were killed. Turkey has a dislocation that runs along the south shore of the Black Sea called the North Anatolian Fault. This fracture slips in the same direction as the San Andreas, the seaward side slips to the left in relation to the inland. The Elburz Fault in neighboring Iran, a branch of which killed 12,000 people on August 31, 1968, lies south of the Caspian Sea. The Elburz motion is the opposite of the Anatolian. The side nearest the Caspian Sea moves to the west. These two faults seem

to merge near the Turkish town of Varto, where 2,400 inhabitants lost their lives in August, 1968.

The mountainous, narrow land of Chile, which hugs the Pacific coast for 2,500 miles, has a notable record of earthquake disasters. Its large seacoast town of Concepción still exists after almost complete destruction in 1570, 1730, 1751, 1835, and a fairly bad quake in 1939. Then in 1960 the hidden forces struck again, moved in some way by the constantly growing mountain chain of the Andes. Among important world communities, Concepción must have top earthquake honors, an achievement few would envy.

On the Sunday afternoon of May 22, 1960, many of the residents of Concepción were out on the streets, celebrating a religious festival. Others had left their homes because a number of small shocks had given warnings to a populace more than ordinarily aware. The big blow came at 3:11. The land began to rock, a motion that felt like being in a small boat in a heavy sea. Parked cars began to roll around. Treetops swayed as if they were in a storm. Buildings began to fall. This first seizure lasted three and one-half minutes.

In the next ten days Concepción and the country for hundreds of miles around it suffered forty-three major shocks and thousands of little tremors. The death toll was comparatively light for an event of such magnitude, but 100,000 houses became unfit for use and one-quarter of Chile's seven million people were homeless in the middle of that country's winter. The quake so disrupted road and rail transportation that emergency aid became severely hampered. It damaged many beautiful mountain lakes, caused landslides, dammed rivers which later burst their new banks in disastrous floods, caused a volcano named Puyehue, dormant since 1905, to erupt, and rearranged the shoreline to such an extent that all charts of Chilean

harbors became obsolete. The quake came from thirty miles deep in the earth. The cause, apparently, was the slippage of one major fault that triggered the motion of many other faults in a mountainous land criss-crossed by deep fractures.

Although doubtless coincidence, earthquakes often do occur on days of particular religious significance. Alaska, source of four percent of all the world's great shocks, received its last major one on Good Friday, 1964. Seismologists call it the most violent of modern times. The best story about this event was written in the U.S. Environmental Science Services Administration Report (Coast and Geodetic Survey) 33 by M. G. Spaeth and S. C. Berkman. Titled *The Tsunami of March 28, 1964, as Recorded at Tide Stations,* it shows the ocean-wide effects of earth movements. In a somewhat condensed version, here is the story.

The Prince William Sound Earthquake of 03:35:14.0 GMT, March 28, 1964 [Three o'clock in the previous afternoon, Alaska time] was one of the largest shocks ever recorded on the North American Continent. The epicenter was located at 61.04° N., 147.73° W., between Crescent City and Unakwik Inlet. The magnitude, as determined by the U.S. Coast and Geodetic Survey, was 8.3 ± 0.33. This earthquake, in addition to generating a major tsunami [sometimes incorrectly called a tidal wave] of record size along much of the Pacific coast of North America, caused several local tsunamis which were responsible for locally heavy damage in various arms and inlets of Prince William Sound. It also generated seiches [oscillating water] in rivers, harbors, channels, lakes, and swimming pools as distant as the U.S. Gulf Coast States.

The major tsunami connected with the Prince William Sound earthquake was generated by a broad crustal warping along a northeast-southwest trending hinge line. South and east of this hinge zone, an area stretching from Kodiak Island

to Kayak Island was uplifted by as much as 50 feet. In many of the harbors and bays, subaqueous landslides occurred and generated highly destructive local waves.

In Seward the first shock sent more than a half-mile-long strip of waterfront facilities sliding into the bay. About thirty minutes later a wave generated by this slide came rushing back into the harbor, creating more destruction and spreading flaming petroleum over the area. The waterfront area of Valdez was destroyed in a similar manner. A captain whose ship was at dockside being unloaded when the big wave came in reported that the vessel was raised 30 feet out of the water and heeled over to an angle of about 70 degrees. Thirty-one people at Valdez lost their lives in the slide and the waves that followed. At Whittier one wave reached a height of 104 feet, port facilities were destroyed by wave action and fire, and 13 people were killed. Many other ocean-side communities in Alaska also received severe damage.

A tsunami, or seismic wave, warning system had been in the process of development for the entire Pacific after an earthquake in the Aleutian Islands on April 1, 1946, created waves that did enormous damage in the Hawaiian Islands a few hours later. The technology for a highly efficient set of alarms, one that could instantly warn communities in distant lands that an earthquake had happened, did not exist at first. Since these very destructive waves may travel as much as 500 miles in an hour, a rapid communication system had to be developed. By May, 1960, the system was in good enough order so that the Hawaiians were warned in sufficient time of the approach of a tsunami from the Chilean earthquake. However, 61 people in the town of Hilo, Hawaii, lost their lives to the waves because they paid no attention to the warning. By the time of the Prince William Sound Earthquake,

the warning network had grown to 45 different stations, from Alaska to Hong Kong, from Japan to Peru.

In Hawaii, seismic waves from Prince William Sound triggered the automatic alarm on the seismograph at the U. S. Coast and Geodetic Survey's Honolulu Observatory eight minutes after the earthquake struck. In the words of the technical report, "The normal working day at the Observatory had ended, and the personnel had returned to their quarters on the Observatory grounds for supper. The food was destined to go uneaten, however, since earthquakes and tsunamis do not respect normal working hours."

Within a few minutes, radio messages had been sent to the seismic observatories belonging to the warning system. Immediate readings on the earthquake were requested and, with the replies, its position could be plotted. Within an hour, its epicenter had been located and messages were sent to the entire network, warning when the waves could be expected at various localities. Information as to the size of the waves was slow coming in because a number of facilities in Alaska which could send the news had been damaged. The U.S. Naval Station at Kodiak, for instance, underwent a 30-foot tsunami wave and all of its radio circuits were under water. Nevertheless, less than three hours after the initial alarm, the Honolulu Observatory sent out a general warning. "This is a tidal wave (seismic sea wave) warning. A severe earthquake has occurred vicinity of Seward, Alaska. A sea wave has been generated which is spreading over the Pacific Ocean. The ETA [expected time of arrival] of the first wave at Oahu is 0900 28 March. The intensity cannot repeat cannot be predicted. However this wave could cause great damage in the Hawaiian Islands and elsewhere

in the Pacific Islands. The danger may last for several hours."

Outside of Alaska, surprisingly, the greatest wave damage from this earthquake came at Crescent City, California. Through a rather freak set of circumstances, part of the wave motion focussed around the Cobb Seamount, a submerged volcano about 400 miles northwest of Crescent City, and from the seamount surged more or less directly to the coastal town. Eleven people were killed, 35 injured, and damage amounted to almost $10 million.

Warning of the wave came at 0708, Greenwich time, or a little after eleven in the evening, local time.

The low-lying and coastal areas were warned and evacuation began immediately. The first two waves caused minor flooding in the business district and many people returned to the area to clean up their places of business, *since past experience showed that Crescent City normally experienced one or two surges with minor flooding during a tsunami.* This premature return to the evacuation area was the cause of most of the fatalities.

The third and fourth waves caught the people who returned to the area after the second wave, and others who had failed to evacuate. Seven people, including the owner and his wife, returned to the Long Branch Tavern to remove the money from the building. Since everything appeared normal, they stopped to have a beer and were also trapped by the third wave. Five of the seven were drowned when the boat in which they were attempting to escape was sucked into Elk Creek and was smashed against the steel grating of the bridge over the mouth of the creek.

The streets of Crescent City were strewn with rubble from demolished buildings, and logs which were swept in from the beaches. Automobiles were heaped in scattered piles, and stock from damaged stores was scattered throughout the area. The third wave picked up a gasoline tank truck parked at

the Texaco station and slammed it through the garage door of the Nickol's Pontiac Building. An electrical junction box just inside the door was knocked loose by the impact and a fire started. The fire destroyed the building and spread back to the Texaco tank farm which burned for three days.

Unusual tides were felt at Lyttleton, New Zealand, 18 hours and 34 minutes after the shock in Alaska and on the Palmer Peninsula in the Antarctic 22 hours and 34 minutes later. Wave action was felt in the U.S. Gulf Coast area within 30 or 40 minutes after the quake. Rivers, lakes, bayous, and waterways experienced surging water. Damage was not great but a number of 4- and 5-foot waves were reported.

Alaska's Good Friday episode made quite a mark for itself. The wave warning system undoubtedly saved lives, where people heeded it. Although this was one of the largest shocks on record, casualties around the Pacific were very slight compared to those caused by other tsunamis. The wave warning operation, however, cannot help those who live too close to the original source of the disturbance. People may take elaborate precautions to protect themselves, but the efforts seem puny in contrast to nature's unleashed power.

Of all Pacific peoples, the Japanese probably show the greatest awareness of earthquakes. They have an old legend about a huge fish whose wild motions shake the world. He can be quelled by a monkey named Kadori Myojin who shakes a magic gourd at the fish. The monkey's powers do not seem terribly strong, however; and the practical Japanese rely much more heavily on scientific research to give them some measure of aid against tremors.

No one can wonder at the Japanese concern. In 1923 the country's two major cities, Tokyo and Yokohama,

came close to complete destruction from a shock that came just at lunchtime on September 1. Many thousands of people jammed the narrow streets. Cooking fires were burning in many homes and public eating places. As usual, the worst effects came from fire and waves, rather than from tumbling buildings. Many homes in the cities were built of bamboo and other light material. The readily combustible ingredients caught fire quickly, causing a raging, destructive blaze impossible to escape. Some 35,000 people looked for safety in an open field next to the Sumida River, but they were burned alive by flying cinders or suffocated by gases. They packed together so closely in their panic that, when the flames died and rescuers could arrive, the charred bodies were locked in a single mass that would not fall over. Waters from the bay also took their toll of lives and houses. In all, more than 100,000 people were killed and more than one-half million homes destroyed.

A modern nation can hardly forget disaster on such a scale. Major new buildings erected since that time have numerous built-in features supposed to resist earthquakes, but no absolute insurance can be given for their safety. Many individual homes still remain fire hazards. No major earthquake has struck these two Japanese metropoles since 1923, but the citizens feel earth tremors almost every day. Newspaper stories discussing the likelihood of another major quake appear frequently.

Complacency in Japan seems unlikely as long as news continues from the little mountain town of Matsushiro, 120 miles northeast of Tokyo. Matsushiro has about 200 micro-quakes every single day. The tremors do not destroy buildings and the natives go on with their farming as if nothing unusual was happening. Unwanted fame has attached itself to Matsushiro for the last several years, par-

ticularly in April and again in August of 1966 when the region experienced 10,000 shocks a day. Some people fled, but most remain, surviving in their situation with Japanese stoicism.

Matsushiro plays an important role in the developing science of earthquake forecasts. From knowledge gained there, seismologists hope to learn how to predict a big earth movement in time to warn Tokyo's nine million people before a truly epic disaster happens.

The study is centered at Tokyo University's Earthquake Research Institute. Nine monitoring stations are located at various points in the Japanese archipelago. It is now known that micro-earthquakes precede a large shock, and the 1966 events in Matsushiro were announced in advance. The research instruments resemble those being used in California, and there is considerable exchange of information and ideas between Japanese and the U.S. scientists, whose nations border on the volatile Pacific.

One Japanese research effort in earthquakes, however, does not seem to have an American parallel. This is the study of fish behavior in advance of shocks. Poetically, at least, it relates to the old legend about the giant fish that rocks the islands. On a number of occasions just before major quakes, unusual species of fish have been caught in waters far from their ordinary habitat. On May 14, 1968, an enormous cuttlefish was caught in shallow water near Aburatsubo, south of Tokyo, two days before that town suffered a major quake. This cuttlefish is ordinarily found only in very deep water some distance from land. Scientists have listed one hundred twenty-seven different times when fish have appeared in unlikely places a day or two before a major earthquake. The reasoning is that fishes may have sensory perceptions unknown to man that warn them to leave a location where an earth-

quake is about to happen. It is known, for instance, that fish can detect ultra-violet rays, which man cannot. Although ultra-violet rays have nothing to do with earthquakes, fish may also have other sensing apparatus that would tell them to move out of an area. While very interesting, the approach to the problem does not sound as if it will be immediately useful to the threatened residents of Tokyo.

Earthquake predictions may come before an understanding of their causes. Perhaps deep earthquakes, the ones that may occur as far as 400 miles down along the Pacific "Ring of Fire," may have different causes from those that bring about seismicity along the Mid-Atlantic Rift; and these, too, may differ from quakes along the San Andreas Fault and the rare quakes experienced in the Mississippi Valley. A number of theories exist at the moment, including one recent one suggesting that earthquakes are caused by slight wobbles in the spin of the earth. A slight change in the earth's axis, which has been detected by star observations, may set off the quakes or, perhaps, the quakes set off the changes in the axis. Whatever theory becomes dominant, it will have to be reconciled to the idea of sea-floor spreading that occupies so many geophysicists today.

IX.

How Does the Earth Get Its Treasures?

No matter how you date the infinite variety of geologic features, it seems certain our earth has an age beyond common sense and human understanding. In a very general way scientists agree about the times when certain events took place (the formation of oil, the death of the dinosaurs, the time of the last Ice Age), but many other things remain without firm dates. Their origins continue to be obscure. We do not understand the creation of many rocks and minerals we classify as wealth. Prospectors have found coal and oil, iron and gold, diamonds, copper, silver, and many other less glamorous but still useful products of the earth without knowing how or why this wealth came to be formed or exists in the places it has been discovered.

The geology books do not generally place much emphasis on a fact that seems to underlie all the diversity of the world's material. Though no one has ever seen it, nor is it likely that they ever will, scientists frequently refer to magma, the molten material beneath us usually kept in check by the earth's crust. Everyone assumes it exists because it must, or many obvious events simply could not take place. What needs stressing is that magma

is not a single substance, like water, that does not change very much from place to place. Magma is more a condition than a chemical formula. Various magmas, in the form of lava when expressed in motion, have quite different constitutions. The volcanic Lipari Islands north of Sicily (which include Stromboli and Monte Vulcano) lie near to one another but the vents of the various volcanoes extrude products quite dissimilar. The assumption is that magma lies in reservoirs which have different compositions. The volcanoes in the Mid-Atlantic Rift pour out other kinds of lavas. These do not resemble the flows from Pacific volcanoes but the flows from all the volcanoes in the Pacific "Ring of Fire" are very much alike. As the shape of things has changed radically in the past, it seems perfectly possible that the location of magma reservoirs and the chemical nature of their contents may also have changed. This seems the fundamental reason for the fact that one area is rich in a certain kind of rock, another has a great concentration of some kind of ore, while gems can only be found in very specific locations.

Some of the oldest metal ore in the world lies in some of the world's oldest exposed rocks. The time was the Proterozoic era, from about 1 billion to 600 million years ago, and the ore was iron. The Proterozoic era had two major glaciations, proving that water existed then, a substance probably necessary for the concentration of iron ores in northern Minnesota and the Lake Superior region, as well as eastern Canada, Sweden, and Brazil. Somewhat younger are the pure copper deposits in Upper Michigan, the 90 percent of the world's nickel found in the Sudbury district of Canada, the nearby silver ores, and the uranium found near the Great Bear Lake in northern Canada and in the Belgian Congo. None of these metals, at least in

such concentrations, seem to have been laid down since the Proterozoic era.

The following era, the Cambrian, produced very little that we today would call wealth, even though it lasted for several hundred million years. Following this was an era known as the Ordovician, a warm period of low-lying land and widespread seas. Even Arctic waters had corals flourishing in them. Oil wells in the Mideast and around Oklahoma City date from the Ordovician.

The Silurian era, from about 360 to 325 million years ago, produced some iron ore, prominently around Birmingham, Alabama, and considerable salt beds along a line running from New York State to Michigan. The oil deposits of Pennsylvania come from the Devonian rocks of 325 to 280 million years ago. The time known as Carboniferous, as its name implies, produced 80 percent of the world's coal supply in North America and Europe, as well as many oil formations west of the Mississippi. (In the United States the Carboniferous is sometimes broken down into the names Mississippian and Pennsylvanian, but these names are not used by geologists in other countries.) The Permian period, which closed out the Paleozoic era, is known primarily for extreme changes in the climate, some of which, in the western part of the United States, produced extremely arid conditions suitable for the deposition of enormous beds of various kinds of salts.

The Triassic and Jurassic periods, which lasted from about 205 million to 135 million years ago, were notable for many invasions and recessions of the sea, for much mountain building, and for the continuing evolution of many species. This was the age of the dinosaurs, and mammals at least began on earth. Sediments from these periods are rich sources of history but, in terms of rocks

and minerals, this long period produced little one might consider material wealth.

The following, Cretaceous, period, one that lasted over 50 million years, deserves the blessings of everyone who sought wealth in America's western mountains. This was the time of the building of the Rockies, the Laramide revolution. The Mexicans and Venezuelans should also praise the Cretaceous. Volcanic activity produced much of the copper, zinc, silver, and gold found in the Rockies. Other geologic activity produced the oil fields of east Texas, as well as the Mexican and Venezuelan fields. In addition, Colorado received 900 billion tons of coal (although much of this is not of great commercial value at present).

The next large period was the Tertiary, so relatively young that it stopped only one million years ago. During the Tertiary the salt domes of the Texas and Louisiana Gulf were formed. Beneath these domes lie the great quantities of sulphur, salt, and particularly oil, being withdrawn from the earth so profitably at the present time. Almost all the oil found in California lies in Tertiary deposits. (The oil fields of Indonesia, Russia, and Rumania are also Tertiary.) The shale oil fields of Colorado and Wyoming, subject of much present controversy, date from this time. The gold found in the streams of California during the rush of 1848 came from earlier rocks in the high mountains, but washed down during the Tertiary, where later prospectors found it by placer mining. The Rockies received new intrusions of precious metals. The Comstock silver lode in Nevada and the gold of Cripple Creek, Colorado, bear Tertiary identification signs. Most of the minerals of Mexico, Central America, and Bolivia also come from the Tertiary period.

Except for the numerous effects of the Ice Ages, the

last million years do not seem to have produced many changes in the world's supply of valuable rocks and minerals. Doubtless movements are going on now, as they always have, but we find them difficult to see during the brief span of our lives. Perhaps someone will perfect an instrument to detect the formation of new oil deposits or veins of gold and silver, but the rate of formation must be too slow for the men who greedily exploit resources, some of which have taken a billion years to form.

Ancestors of our species began using rocks as weapons and tools at some unknown date in the past, but one that seems to be receding with each new discovery of the anthropologists. They also used pretty stones and shells for ornaments. At a variously dated time, perhaps five or six thousand years ago, men discovered how to make metals out of various ores. Progress was very slow at first but has been accelerating ever since the first enemy was wounded by a bronze-tipped spear. Not to labor the obvious, the human use of earth materials has transformed the world.

The search for the raw stuff needed in technology has led people almost everywhere on the land's one-third of the planet. Probably "Gold" has been the loudest cry, at least until the age of oil, but curious men have tested everything they could find to see if it did not have some purpose. Such things as ore bearing uranium had to wait until the men in the laboratories found a use for it, but other discoveries were tested, usually by trial and error, until someone saw what could be done with them. It took many years to realize that the oil that seeped into Pennsylvania wells, fouling the water, could be used to run engines.

Most of the men seeking treasures from the earth were practical people. As long as the search was easy, they asked

no theoretical questions. But, as has been said, "geology grew up around ore deposits." That is because many of the things most desired did not just sit on the surface waiting to be picked up. Precious metals, in particular, often hid within mountains. Where were they likely to be found? What are the rules that govern the course of a vein of silver? From there the step is a brief one. What causes the rocks and minerals to form? What governs their location?

The prospectors and the geologists now know a very considerable amount: the most likely parts of the world, the characteristic terrain and accompanying rocks, the probable direction of a strike and a good guess as to the yield. These are the practical matters, the ones that pay off. In a recent book on ores, however, two scientists wrote, "Many of the most fundamental problems relating to the transportation and deposition of ore materials remain unsettled." * Unknowns quite obviously exist in every science.

At Delft, Holland, in 1963, a distinguished international group of geologists met in symposium to discuss the subject of "ore genesis." (No more basic question exists than "How did it begin"; it seems unanswerable in every field from astronomy to fights between children.) The meeting was led by G. C. Amstertz, professor at Heidelberg University in Germany, who threw sarcasm at fashions in theories about the origin of ores. He thought little of explanations that spoke of "hidden causes at 'unknown depths.'" This is much too easy an out and says nothing. Dr. Amstertz had little time either for the "myth of replacement." The symposium concluded with the general feeling that a solution had not been achieved.

* Charles Park, Jr., and Roy MacDiarmid, *Ore Deposits* (San Francisco: W. F. Freeman, 1964).

The genesis of many of the commonest materials remains in dispute. Granite, for instance, may not only be the product of the solidification of liquid magma. Field work suggests that granite may also be produced from pre-existing solid rock by something called "granitization." This would be a process of replacement, perhaps with volcanic solutions; a process derided at the Dutch symposium as begging the question. The granite controversy has been going on for some years. Why no granite has flowed for millions of years remains to be explained. No great question exists today about basalt, except perhaps the elementary one that asks why it flows when it does.

Iron ore poses a number of source problems. Iron exists in very dilute solution over much of the globe, but why is it concentrated so heavily in just a few locations? Apparently the iron dissolved out of basic volcanic rocks, but in some iron-rich areas there is no evidence of old volcanic activity. The soil in which it is found around Lake Superior is basically sedimentary. The ore around Lake Superior has been weathered and leached so that high concentrations of iron are left. But one of the ranges, the Mesabi, has been twice as prolific as the next ten combined. Can the concentration be due just to a slightly different tilt of the underlying rocks? Is it possible bacteria concentrated the iron rich ores in some manner? The finest iron ores in the world, those of northern Minnesota, have been just about exhausted but it remains interesting to wonder how they got there.

Common salt in some areas also presents problems to geologists. It underlies a good deal of New York State and Ohio, but in Michigan the sheet of salt is sometimes 1,000 feet thick. What kind of ocean created such a deposit? This part of the world was covered by the sea during Silurian times. The sea covered much of west

Texas during Permian times but left beds of gypsum instead of salt. Why do the deposits differ? Could the composition of Silurian and Permian salt water have been different? Of salt it might also be asked why, in the Gulf of Mexico, it concentrated in domes that entrapped oil and sulfur.

Three minerals known as evaporites, which have considerable commercial importance, also give geologists pause. All three occur in densities that seem beyond explanation. Potassium occurs as potash in New Mexico, sodium as sodium carbonate in southwest Wyoming, and boron as borax in the Mojave Desert of California. All three beds have been mined extensively for many years without any signs of giving out.

In discussing these beds of evaporites, though he might have been talking about many other formations as well, a scientist wrote:

> It seems to me another illustration of the remarkable phenomenon of geology wherein a rare combination of factors provides the necessary environment for the formation of an unusual mineral and then persists without significant change until huge quantities of the rare product have been formed. . . . I confess that contemplation of these laboratories of nature where a complex dynamic system remains so long in apparent perfect balance fills me with something very close to childlike wonder.*

A similar striking feature are the deposits of phosphate that underlie much of Idaho, Wyoming, Utah, and parts of neighboring states. Many papers have been written discussing their origin. The lands were once beneath what is called the Phosphoria Sea, said to have been 3,000 feet

* W. H. Bradley, "Limnology and the Eocene Lakes of the Rocky Mountain Region," *Bulletin of the Geological Society of America,* 59 (1948), 643.

deep during the Permian time. The deposits of phosphate are extraordinarily thick, and no other area in the world has anything comparable. Wonders exist all over the world, but the west of the United States seems to have an unusual share.

Numerous other geological mysteries also exist. The kaolite and illite clays very often used in bricks and tile developed in ancient swamps. Eleven theories exist to explain the origin of those swamps. The nitrates mined on the beaches of Chile and used around the world as fertilizer have been described as the guano droppings from birds, but this turns out to be an exaggeration and half-a-dozen causes are now given for the Chilean phenomenon. The beds of lead found in various mines may be caused by hot magmatic water circulating through fractures and causing restructuring of rocks, or they may be beds of sediment in which the lead has deposited due to chemical precipitation. Manganese ores may be caused by volcanic intrusion, or were they caused by bacterial precipitation? The fields of Witwatersrand in South Africa have been the leading gold producers anywhere for many years, but no one has decided whether the gold comes from distant mountains and is washed down or if it is produced underground, by hot magmatic water.

The name petroleum comes from the Latin and is made up of two words meaning rock and oil. Everyone knows that oil is made up of tiny plants and animals who died many millions of years ago, were buried, compressed, heated, and somehow emerged as fuel to burn in your car. Still, oil remains as much a scientific problem as any other mineral. Does it have to have been formed under the sea? What makes it concentrate in certain areas? Why do some organic sediments make oil while others become coal? Or shale oil or natural gas? What exactly happens

in the process of formation? These questions all have interesting answers, but they are hypotheses, not the final word.

The commercial search for oil has led to many advances in geophysical exploration and technology. Considerable geological theory has been developed by the numerous scientists employed in the oil industry to find new resources. The continents, the islands, and the sea bed itself have been mapped, drilled, and pounded with dynamite in tremendous detail, so that it would seem all possible oil reserves must long since be known. Still, new finds continue. In recent years the floor of the North Sea has been tapped, yielding tremendous quantities of natural gas. At Prudhoe Bay in Alaska, 120 miles east of Point Barrow, the last outpost of civilization above the Arctic Circle, oil companies have found a store of wealth variously estimated as between 5 and 40 billion gallons. The scientific voyage of the *Glomar Challenger,* drilling several thousands of feet, under two and one-half miles of water, produced samples of oil in an environment that will be a solid challenge to exploitation if further studies show that oil in quantities exists at such depths in the Gulf of Mexico. The discoveries in Alaska and the deep waters of the Gulf of Mexico will be studied to see if they confirm, or challenge, theories about the past history of the earth. The technology developed to make use of these discoveries, if a profit can be shown, will soon be employed by the science researchers.

As has been mentioned, two of the most important tools in the study of submarine geology are direct adaptations of skills learned by the oil industry. Dr. Maurice Ewing of Lamont-Doherty, who introduced seismic shooting, "man-made earthquakes," into the sea to determine the depth of the sediment, learned his technique while work-

ing during summer vacations in the oil fields. The drilling done by the *Glomar Challenger* is done using methods for deep-sea work first invented by oil prospectors.

The search for oil and minerals will continue on land but more and more attention is being paid to the sea as the Far West of the future. No doubt exists about the future of oil as a marine resource. How it got there may remain a question, one whose answer would be useful to guide further exploration, but the oil people already have enough clues about likely places for drilling that they can go ahead without final answers.

A number of other minerals of potential value exist in the sea about which no particular mystery exists. The questions are essentially economic. How can the materials be extracted profitably? Although the water itself contains all the elements on earth, they are so dilute that only salt, bromine for gasoline anti-knock fluid, and water for desalination are regularly taken from it. Phosphorite or phosphate rock, derived primarily from the calcium phosphate of countless billions of marine shells, exists in quantity off Florida and southern California (as well as many other places in the world). Some of this is being mined for use as an excellent fertilizer, and more will certainly be taken when the demand increases.

Diamonds have been profitably dredged from the Atlantic off South Africa. These gems certainly washed down the rivers from known land deposits. Gold is similarly dredged in the sands and the shallow waters of Alaska and has the same source. Surveys now being conducted in the Bering Sea, near Nome, Alaska, home port of the original Gold Rush, look for commercial quantities of gold, tin, platinum, and petroleum. When the sea level was much lower during the Ice Ages, it is believed these metals may have been deposited on beaches that are now

drowned. This area also contains sedimentary rock, raising the possibility of oil deposits.

A very tantalizing mineral found in the sea is manganese, widely used as an alloy of steel. The United States has a very poor supply of manganese and must import 90 percent of what it consumes. It exists in nodules over vast amounts of the ocean floor, ordinarily in combination with iron, cobalt, nickel, copper, or phosphates. Often described as rocks that resemble baked potatoes, the nodules also come the size and shape of Ping-Pong balls or cannonballs. Sometimes the manganese is found in wide, flat hunks known as pavement. One such piece was recovered that weighed 1,700 pounds. The color is usually brownish black and objects such as shark's teeth and whale bone ears are often found imbedded in nodules.

These strange objects were first dredged by the British ship *Challenger* during its world-wide expedition in the 1870s, and they were found on every ocean floor. Nodules have been known to exist on the Blake Plateau off South Carolina, Georgia, and Florida ever since serious surveys of the area began in the late nineteenth century. They seem more abundant here than in many other parts of the Atlantic but perhaps only because the fast-moving Gulf Stream sweeps the bottom clean of sediment, making them easier to recover. A number of dredging and photographic surveys of the Blake Plateau have been made in recent years. That of the U.S. Coast and Geodetic Survey ship *Discoverer* in 1967, over an area equal in size and shape to the combined states of Vermont and New Hampshire, found manganese nodules at an average depth of one-half mile of water about every second sampling. Sometimes the dredge recovered several hundred nodules in a single haul. Nodules in the Pacific, in even deeper water, are said to be much more abundant.

Scientists consider the nodules authigenic, "generated on the spot." They were merely curiosities until dredgings in the 1950s found samples very rich in cobalt. More research has shown them to be quite common. Estimates say they may cover as much as 10 percent of the deep ocean floor, though this can only be a guess, since so little of the sea has been studied in detail.

A round nodule, sawed in half, reveals growth rings similar to the growth rings seen in a log of wood. The rings differ in width, as if there were rapid periods of growth and periods of drought. It seems they do not grow when covered by sediment and only resume development when a bottom current clears the area where they are deposited. This would explain their profusion on the Blake Plateau.

One theory of the nodules' origin says they result from sea water too saturated with manganese and iron. The manganese derives from volcanic eruptions and from streams carrying it from the land. Since the saturated sea water cannot hold any more of these minerals, they must precipitate and, in doing so, they pick up particles of whatever other metals are locally available. Having fallen to the sea floor, this precipitate settles around any hard object available. The rate of growth is very slow. The percent of manganese in the nodules seems to be increasing in recent years since nodules at the surface contain much more of this mineral than those buried in the sediment. Even a small nodule may be a million years old. The chemical composition of these nodules is unlike anything else on earth. Their existence still amazes geologists.

Naturally, the great amounts of nodules known to lie in the sea interest commerce. A special ship was built at Newport News, Virginia, to experiment in mining the nodule deposits on the Blake Plateau. Although the

interests involved kept their operations a secret, it is known that the work went on for some time, at great expense, and then was evidently abandoned. Apparently it was difficult to dredge sufficient nodules even at a half-mile depth, in the 4- or 5-knot Gulf Stream, or perhaps the chemistry of the nodules was too complex to break down into the various ores. Mining the more abundant nodules in the Pacific may be equally troublesome because, even though no Gulf Stream would interfere, the nodules often lie in 12,000 feet of water and they are many hundreds of miles farther from land. An additional problem in all ocean mining is a legal one. No nation owns the sea floor beyond its continental shelf and therefore cannot give a mining company the exclusive right to a particular part of the bottom. It would take a hardy capitalist to invest millions of dollars in an operation that could be invaded by any other entrepreneur at his pleasure.

Yet, if the manganese nodules present problems in science, economics, and international affairs, they are dwarfed by the complications presented by the bizarre area in the Red Sea sometimes known as the "hot spot." Interested in this startling new discovery are the United Nations, a dozen Foreign Offices, as many scientific institutions, chemists, geophysicists, volcanologists, international lawyers, and numerous mining companies.

It all began innocently enough in 1948 while a Swedish oceanographic ship, the *Albatross,* was traversing the narrow arm of the sea between Saudi Arabia and the Sudan. Observers aboard noted that the bottom sea water was unusually hot and salty. The observation was duly reported in the literature and then neglected. The Woods Hole ship *Atlantis I* stopped briefly in the area in 1958 and discovered the same phenomenon, which they called the

"funny water." A tight schedule obliged the ship to hurry on to the Indian Ocean before it could carry out a complete study.

This part of the Red Sea was first truly investigated in 1963 when the British ship *Discovery* and the American *Atlantis II* revisited. The British scientists could not find any normal life below 2,400 feet, and at 3,000 feet they recorded a temperature of 70 degrees Fahrenheit, almost twice that of the Atlantic at a similar location and depth. The British named the area they surveyed the Discovery Deep. It measures about two and one-half miles long and two miles wide.

Atlantis II lowered sensors to 6,000 feet and found a temperature of 135 degrees Fahrenheit. (They used a new kind of thermometer since the ones previously used in the sea could not withstand such heat.) The salinity was ten times that of ordinary sea water. The concentration of metals was very high. The Atlantis II Deep is about four miles by eight miles.

In the fall of 1966, the Woods Hole ship *Chain* went to the Red Sea to investigate further. A third deep was found and duly named. These are three pools of water, all at least a mile deep, separated by ridges that prevent the waters from mixing. The largest, the Atlantis II, has three calderas, the large craters left behind by the collapse of a volcano's central cone. These hot spots, of course, are all centered in the Rift valley.

After the return of the *Chain,* newspapers began to publish reports on this astonishing place. Their accounts made much of the high mineral content of the ocean bottom, "the richest concentration of underwater ores ever found." The gold, silver, zinc, and copper in the Atlantis II Deep all by itself are estimated to be worth a billion and a half dollars, and this does not include the abundant iron and

manganese also to be found there. Dr. E. T. Degens and Dr. D. A. Ross wrote in the Woods Hole magazine, *Oceanus,* that no such colorful sediments from the bottom of the sea had ever been encountered before. The fantastic variety included all shades of white, black, red, green, blue, and yellow.

In 1967 the Coast and Geodetic Survey's *Oceanographer* stopped in the Red Sea while on a world-wide scientific cruise. It found a fourth hot spot, 340 miles north of the others. It began at a depth of 4,800 feet and continued for 300 feet to the bottom.

Because these deeps are so valuable, there is a great deal of speculation about who can lay claim to them. Like many other rifts, the area lies midway between two continents, two nations, Saudi Arabia and the Sudan, on no nation's continental shelf. (The island of Malta has proposed that all such territory should belong to the United Nations.) At present there are technical methods to explore the deeps to the necessary extent, but no economical method of mining them has been worked out. When the techniques are worked out, the Red Sea "hot spots" will be important news.

Meanwhile, how did they get there? They are on the Rift. In this active area did hot water, heated in a reservoir of magma, circulate in faults or fractures to release this vast store of minerals? The hot spot seems very young, its age perhaps measured only in thousands of years. Is it the modern counterpart of ancient ore-forming processes? Did eruption bring the saturated water to the ocean floor where it immediately sank due to its weight? Why is this phenomenon so salty? Could the Red Sea once have been a salt lake, such as the one in Utah, that was filled again when the Rift fractured the sill at the Gulf of Aden that separates it from the Indian Ocean, or could the Red Sea

have been refilled when the sea level rose again at the end of the last Ice Age? One might also ask if hot water elsewhere in the Rift is creating more funny spots? Global explorers will probably have little trouble with financing once this possibility is generally known.

X.

The Sea of Perpetual Motion

OCEANOGRAPHY has become an increasingly glamorous and fashionable word in recent years. The reasons are clear and good. Speaking only of the United States' experience, the idea of the sea has had a checkered past. Most immigrants from Europe, beginning with the Pilgrims, found crossing the Atlantic a very unpleasant experience, and a fear, a dread of the ocean, passed on to their descendants. On the other hand, the only American heroes in the War of 1812 were naval ones. Later, whaling captured the imagination of adventurous boys like Herman Melville, and many New Englanders founded their fortunes on the capture of cetaceans. Being a sailor, of course, gave a man a social position similar to that of an outcast, but toward the end of the century, men began to buy yachts, and the advent of the luxury liners gave a cachet to ocean voyages. The immensely popular victory of the Spanish-American War was almost entirely due to the U.S. Navy, and, with the exception of Teddy Roosevelt, all the men who emerged famous from it were sailors. The First World War did little for the reputation of the Navy, but the Second put it on the map. A million young men saw the sea for the first time. The great fleets

that steamed America to victory in the Pacific captured the national imagination with their size, their power, and their success. The technology and the mostly secret science that went into that victory were gradually revealed; and the U.S. Navy, realizing how little its own medium, the sea, was actually understood, became the nation's major source of funds for basic research. (Not excluding funds for atomic energy, missiles, and satellites, which were essentially programs in engineering.)

The American public took up Scuba diving (a French invention), snorkels (a German development), boating (as they could afford it), marveled at Cousteau's books and movies, read with some wonder of the exploits of the atomic submarines, and became interested in the sea in quickly increasing numbers.

Overwhelmed by the federal funds available to them and looking for young scientists to help them spend it, the oceanographers began to unbend and tell the world what they were doing. Men in business, hearing much boom talk of the new frontier, began dreaming of vast fortunes. Gloomy thinkers who worried about feeding the future world's growing population looked to the ocean's countless fish to solve their problems. Oceanography was no longer the private little club of a few hundred pure scientists.

Yet the pure scientists are holding their ground because the gap between public understanding of studies of the sea and the actual complexity (and sophistication) of the problems is very great. The purest kind of oceanography, the study of the behavior of the sea itself, is highly technical, mathematical, and only those at least well on their way to a Doctor's degree are capable of adding much to the present knowledge.

Nevertheless, the general problems of physical oceanog-

raphy are not beyond the layman, and there is nothing difficult at all about understanding its importance. In immediate terms, the sea has as much to do with our weather as any other single factor. Almost all the rain west of the Mississippi comes from the Pacific. Ninety percent of the rain that falls on the United States east of the Mississippi comes from the Gulf of Mexico. Much of the wind that drives across the land has come from the sea. That most spectacular American wind, the hurricane, is born in the ocean. The laws behind these meteorological events are very incompletely understood.

No one who uses the sea for recreation need be told how important the state of the sea is in determining a good or bad day at the beach. Jellyfish, Portuguese men of war, immense breakers, storm surges, shark scares, unusually cold water, red tides, all these and other phenomena can ruin a person's swimming. Physical oceanographers study why the sea changes in these ways. They also study why the sea builds up one beach and destroys another.

To everyone out upon it, or under it, the behavior of the ocean, at present very hard to predict, means the difference between success or frustration, failure, or even disaster. The animals sought by fishermen follow the changing currents to keep in water that has a temperature congenial to them. Boats and ships may find the sea the most exhilarating surface in the world or a mean, choppy, rough tormentor. Military vessels find the behavior of the sea as important as the actions of their enemies.

The student of the earth's past, the geologist, finds the sea running across his path almost everywhere, even though he may only be trying to reconstruct the story of the land. The sea has changed the map of the world many times.

Whether our continents remained stationary, or roamed

around as suggested by the evidence of paleomagnetism and continental drift, the boundaries between sea and land underwent a great number of revisions during the long ages that scientists have only recently been discovering. As the life of the planet is seen to be more on the order of four or five billion years, rather than a mere one or two billion, the possibilities of large-scale revolutions between sea and land become even greater.

The first sure evidence of the existence of water comes from the dimly known Proterozoic era about a billion years ago. Evidence of water erosion and sedimentation exists as well as signs of primitive life, deposits of carbon and limestone, though no fossils as yet. The water must have obeyed the same laws of physical motion that exist today, so there were waves and tides and currents, but what land masses did to them as they swept around the world can only be guessed at this time.

Did a difference between fresh and sea water exist during Proterozoic times? The usual explanation for the saltiness of the sea is that it came from minerals washed off the land. In the earliest days of water, therefore, it should have been essentially fresh. Volcanic explosions, however, do produce chlorine among their many other effusions, and so perhaps the sea had some sodium chloride dissolved in it almost from the beginning. The chemical content of the sea that long ago is not an idle question, though it may seem so. Until the sea became the complicated sort of soup it is today, our own species could not have evolved. The human body has all the same elements, in almost the same proportions, as the water of the ocean. Until the ocean reached its present state, human beings as we know them were not a possibility. It might be interesting to learn how long ago we became chemically possible.

Wherever the present North America lay on the globe

in the following era, the Cambrian, much of it lay under the sea. Roughly speaking, this included southern California, Nevada, Arizona, Oklahoma, western Canada, Newfoundland, Nova Scotia, and eastern New England. Later in the Cambrian the seas advanced on the land and about one-third of the continent was covered. Then the land rose and the Cambrian seas retreated.

In the subsequent, Ordovician, time, about 425 million years ago, more of North America was under water than at any time since then. In general, the east and west coasts were mountainous while the central area of the continent was usually low and flat. In the following 300 and more million years, the seas invaded, then receded, mountains were formed and then worn down, volcanoes erupted and then died. All left their deposits on the earth, the relics that give the geologists the clues to the remarkable story they tell. The story is one of cycles, great building and then subsidence.

These cycles have had a number of explanations. A simple one for a rising area is that the land is regaining its natural level after being depressed by an ice sheet. This is demonstrably going on in Scandinavia, particularly Finland, where the land is rising about an inch every year, recovering from the effects of the Ice Age that ended 11,000 years ago. Building on a much more spectacular scale can be seen in the great volcanic peaks of the Pacific Northwest and in the Rocky Mountains and Sierra Nevada, which have been uplifted thousands of feet by compression. A great land mass may rise as it becomes lighter, due to erosion, which also deposits enormous amounts of sediment on the ocean floor, causing it to subside. The sea level may also rise due to the displacement of water by eroded material from the land, the creation of great volcanic islands, such as the Hawaiian chain, or by the melt-

ing that follows the end of an Ice Age. Minor factors in land building and destruction are waves that chew up rocky coasts, corals that create new land, and currents such as the Gulf Stream, which eats away the continental shelf off southern Florida but creates large spits of sand such as Cape Kennedy and Cape Hatteras.

Such ceaseless action explains why the maps change, even though on a scale of time beyond our understanding. For the past 60 million years the lands that are now Canada and the United States have changed their coastlines very little and the inundations have been minor. A few changes might be mentioned, however, to show that the world has not been completely inactive. In these Tertiary times the great mountains of western North America were built; and, 20 million years ago, Florida emerged from the sea dripping and covered with limestone. The mile-high sheets of the Ice Ages did come, leaving Cape Cod and Long Island behind on their withdrawal. More dramatic changes, however, came to the seas just south of the present United States.

One of the least known effects of this endless contest between land and sea is what the changes have done to the ocean currents. By general agreement, the ocean currents have an enormous effect on the weather, although the detailed mechanisms by which they do remain one of the mysteries. For the entire North Atlantic, what is now called the Gulf Stream "system" is a major modifier. To understand what the Gulf Stream may have been like in the geological past, it may be well to describe briefly how it is understood to work today.

Ocean currents are like vast rivers, without any stream beds to guide them, that run through the comparatively motionless seas about them. Many forces affect their behavior. Water at the surface in the tropics is quite warm, and at the poles it is

very cold. Warm water expands and becomes lighter; colder water—up to the point of freezing, when it starts to expand—becomes dense and heavy. As the cold polar water sinks, the warm water from the Equator flows out to take its place. Thus, the polar water moves along the bottom toward the tropics, while tropical water moves north and south in the direction of the poles.

The process is speeded up by the prevailing winds on either side of the Equator (the trade winds) which regularly blow toward the west because of the earth's eternal rotation. The warm surface water near the Equator is therefore pushed generally westward by these winds. When these currents are blocked by continents they have to move somewhere. In the northern hemisphere they turn toward the right and in the southern hemisphere they turn toward the left—a phenomenon known as the Coriolis effect.*

The way the Atlantic basin is presently constructed, the North Equatorial Current strikes South America above the equator at a point where the land slopes north and west. The South Equatorial Current also strikes land with the same sloping direction, and much of this water runs north across the equator, apparently contrary to the laws of physics, and joins its twin current moving toward the Caribbean. On the way, it picks up fresh water from the Amazon.

The inland sea of the Caribbean is guarded by the West Indies chain of islands, and underwater sills connect the little bits of land. Much of the current does not enter but continues to flow north and west, outside the chain. The water that does enter flows in the same direction. It picks up more heat energy from the tropical sun. A strong wind blows almost constantly, pushing it along to the west. Off

* Peter Briggs, *Water: The Vital Essence* (New York: Harper and Row, 1967).

the south coast of the island of Curaçao, near the mainland of Venezuela, the vast strength and speed of the current can be seen as one watches little schooners skim along in its flow or fight doggedly to make headway against it.

The Coriolis force which makes fluids veer to the right drives the water through the narrow Yucatan Channel between Mexico and Cuba and into the Gulf of Mexico. Sailors once believed, incorrectly, that the stream actually began here, and that is how it got its name.

In the Gulf some water eddies about but the main flow is now to the east again. The sea level is higher in the Gulf than off Florida, and thus the current is flowing downhill. After passing along the north coast of Cuba, it reaches the southern tip of Florida where it is forced into the narrow channel between that peninsula and the shallows of the Bahama Islands.

Now called the Florida Current, it is forced north until, near Bimini (one of the world's great fishing grounds), it encounters the water that has been flowing outside the islands. Water from the Sargasso Sea, an unmeasured amount, also joins what is now officially the Gulf Stream. Doubled in volume, greatly increased in depth and velocity, the stream proceeds up the U.S. east coast until it heads out toward sea at Cape Hatteras. Now on a northeasterly course, still under the power of the Coriolis law, much of the stream goes to the vicinity of the Grand Banks of Newfoundland where it strikes the cold, south-flowing Labrador Current. (This meeting creates some historic fogs and a fishery that has shaped history since the Portuguese discovered it almost 500 years ago.)

The somewhat battered Gulf Stream then heads toward Europe. A scant two percent goes toward the Arctic Ocean but this is enough to keep the sea south of Iceland open to navigation, give some warmth to Norway, and even

make life possible in Spitzbergen, well above the Arctic Circle. More of the water strikes a course to Great Britain and France and though much of it does not physically reach there, it warms the prevailing winds sufficiently so that England, in the same latitude as Labrador, has a population of almost 50 million. The variations in the flow of the Gulf Stream toward Europe are considerable and produce changes in the weather there that are at present hard to predict. An understanding of its erratic pulses would be of great benefit to the eastern side of the Atlantic, one of many reasons why so much research effort goes into this flow of warm water.

Since the Gulf Stream cannot always have followed the same direction as it does today, what happened to Europe in times past remains a problem. Marine fossils show that parts of Central America and particularly the Isthmus of Panama have been covered by the sea a number of times in only the last 60 million years. When the land barrier did not exist, the natural course for much of the Caribbean current must have been to continue west and out into the Pacific. Did some of this water even reach and warm Alaska?

If the West Indies barrier islands existed at the same time, that warm water, at least, might have affected Europe; but many of the Leeward and Windward Islands seem to be quite young; and it becomes difficult to guess what would happen without them.

The ancient Gulf Stream poses a problem in that even a submerged Florida and the Bahama reefs are no more than 75 million years old, and thus were in no position before that time to give the stream direction. Florida only came up above sea level 20 million years ago, and before then water might well have easily flowed over it. Cuba, at present, diverts the Gulf Stream but does not stop it.

When the island appeared about 135 million years ago, it must have caused a considerable change in the climate of lands far removed. Then, about 10 million years ago, a ridge, a mass of land above sea level, appears from fossil evidence to have extended from Mexico's Yucatan Peninsula to Cuba, then to Hispaniola, to Puerto Rico and the Virgin Islands, excepting St. Croix. Such a long barrier would force the Gulf Stream into very unusual patterns. In even more distant times, if no islands barred the way and inland North America lay under the sea, the current must certainly have invaded the present land to a considerable extent. What was Illinois like when deep blue waters of the Caribbean flowed nearby?

From all this, clearly, the ancient history of the ocean currents is not easy to write. The present Gulf Stream itself has been giving scientists trouble ever since Ben Franklin first publicized it about 200 years ago. He was not, in this instance, the discoverer. Leonardo da Vinci had reasoned that something like it must exist, since the water warmed at the equator would have to flow toward the poles. The first eyewitness account now known on paper comes from the sixteenth-century explorer, Sebastian Cabot. In typical sailor fashion, he complained that the warm waters found in certain parts of the Atlantic were ruining the beer kept cooling in the ship's hold, causing it to ferment. Captains sailing later from Spain, beginning with Columbus, discovered the great circular current and employed it during their voyages but tried to keep its existence a national secret.

In the year 1769, Benjamin Franklin was working in London as Postmaster General for the American colonies. He knew that the mail carried by the English packets took an unreasonably long time to reach Boston. Franklin discussed the matter with a Nantucket whaler called Timothy

Folger. Like other American sailors, Folger had become well acquainted with the current in the pursuit of his trade. Franklin learned the details from the skipper and published the first scientific chart of the water of the North Atlantic. American seamen willingly used it but for a considerable time the British scorned the information because it came from simple, colonial fishermen. Franklin called the Gulf Stream an "ocean river" and believed that it was caused entirely by the wind.

As the spirit of the scientific inquiry began to flourish in the nineteenth century, the Gulf Stream interested more and more people, particularly Americans. Among these were Matthew Maury, one of oceanography's founders; A. D. Bache, a descendant of Franklin; Alexander Agassiz, whose father proclaimed the Ice Ages to the world; various officers of the U.S. Coast and Geodetic Survey, and John Elliot Pillsbury of the U.S. Navy. Pillsbury actually anchored his ship, the *Blake,* in the swift Straits of Florida for a total of more than a thousand hours to measure the current. In a report on his work, Pillsbury in 1890 wrote:

> Man stands with bowed head in the presence of nature's visible grandeurs, such as towering mountains, precipices or icebergs, forests of immense trees, grand rivers or waterfalls. He realizes the force of waves that can sweep away lighthouses or toss an ocean steamer about like a cork.
>
> In a vessel floating on the Gulf Stream, one sees nothing of the current and knows nothing but what experience tells him; but to be anchored in its depths far out of sight of land, and to see the mighty torrent rushing past at a speed of three to four miles per hour, day after day and day after day, one begins to think that all the wonders of the world combined cannot equal this one river in the ocean.

The officers of the British expedition aboard the *Chal-*

lenger and Prince Albert of Monaco, an oceanographic enthusiast, also concerned themselves with this vast system. Gradually it became very clear that the Gulf Stream, as a natural phenomenon, has few more fascinating rivals on earth.

The concept of the stream seems simple enough. An enormous, warm body of water, much deeper blue than the surrounding water because of its saltiness, flows west across the Atlantic, in and around the Caribbean and Gulf of Mexico, out past Florida and up to Cape Hatteras, then out to sea toward Newfoundland and Europe. Gradually it thins out. Much of the water heads south, off Europe. When the trade winds pick it up off Portugal and Africa, the water heads west again in another cycle.

Investigations have revealed many complications to add to this simple picture.

The Gulf Stream is moody. At times its volume changes inexplicably. In December, 1952, for instance, its volume at one station rose temporarily from 20 to 50 million cubic yards per second.

It creates a unique body of water known as the Sargasso Sea. This deserted stretch is located in what is known as the "horse latitudes"—because horses carried as cargo were thrown overboard when ships becalmed lacked water to keep them alive—was long feared by sailors who threatened mutiny rather than sail through it. The world has no other such sea. The Japan or Kuroshio Current in the Pacific resembles the Gulf Stream in many ways. Why has it no Sargasso Sea?

The Gulf Stream does not really flow like a river at all times. Often it moves in fits and starts. It meanders. The right-hand, or seaward side, is considerably higher than the left-hand, or side toward the continent. The right-hand side acts as if jet-propelled while the meanders occur

on the left. No fixed rule has been found to predict the meanders, though very careful records have been kept over long periods of time to establish a pattern. Some natural law must exist to explain the variations, but none is yet revealed. Does the stream meander more after heading out from Cape Hatteras because it has no coastline to guide it?

Does the stream derive most of its power from the wind, the heat differential, or the rotation of the earth?

How does the Gulf Stream affect the distribution of marine life? (Timothy Folger said whales were found along its borders but not within the stream itself.)

The Gulf Stream carries a flow of water once calculated to be 1,000 times greater than the flow of the Amazon. Where does so much water go? It is very difficult at present to measure the volume that flows across the Atlantic but evidently most of it does not reach Europe.* Is there a countercurrent that flows underneath the Gulf Stream in the opposite direction? Several tests with a deep Swallow-float and a little submersible called *Aluminaut* seem to indicate such a countercurrent, but it has been asked how the countercurrent can travel south of Cape Hatteras since, at that point, the Gulf Stream reaches all the way to the sea floor. (As a corollary, where does the Labrador Current, coming from the north, go after confronting the Gulf Stream on the Grand Banks of Newfoundland? Some continues south to cool the shores of New England, but the flow in this area does not seem to account for all the water involved.)

Do the Mid-Atlantic Ridge and the various sea-

* To explain the disappearance of so much Gulf Stream water somewhere in the Atlantic, F. C. Fuglister of Woods Hole suggested the analogy of a piece of string. If you bend the string in great loops, you can condense a great deal of string into a fairly small distance.

mounts have any effect on the direction of the stream? Yes, apparently.

The U.S. Environmental Science Services Administration summed up the problem in one way while announcing a research program with Nova University off the coast of North Carolina. It is to be "The most detailed and most accurate survey ever made of the total structure of a segment of the Gulf Stream. . . . Determination of the stream's speed, volume, direction, and source, and of its temperature from the ocean surface to the sea floor, will be used in a study of the physical processes of the Gulf Stream."

According to Dr. William von Arx, the Gulf Stream problem is that the oceans and atmosphere form a system in which many different physical systems play interacting roles. It is hardly possible to study oceanic circulation out of context. And the most obvious differences, which scientists might be tempted to separate for study, may not be the most important. The meander pattern is not so great that the general circulation pattern of the North Atlantic is changed. The tides may move the stream bodily from one side to the other as much as ten miles, but it returns. Ordinary cyclones and even hurricanes do not modify Gulf Stream circulation noticeably. But less conspicuous variations do create considerable changes. "In the study of the Gulf Stream we find all the essentials of the problem facing those who concern themselves with the study of the natural world; how can potentially simple and understandable processes be separated from the general complex of natural phenomena." * In other words, one might ask, how can we make the Gulf Stream stand still to examine it when everything involved is in perpetual motion?

* William von Arx, *An Introduction to Physical Oceanography* (Reading, Mass.: Addison-Wesley, 1962).

The Woods Hole Oceanographic Institution has been a leader in the study of the Gulf Stream ever since Professor Henry B. Bigelow and his student, Columbus O'Donnell Iselin, founded it in 1930. One of the country's leading experts on the stream, F. C. Fuglister of Woods Hole, has specialized in the "rings" it forms as it meanders. The term "eddies" has been used by other scientists, but Fuglister believes that "rings" is more exact, since the stream often makes an ellipse and finds itself meeting itself. These rings are sometimes so big that it may take a ship several days to circumnavigate one.

No one has counted the times that ships from Woods Hole have taken the measure of the Gulf Stream, but special expeditions have been made on a number of occasions, and every time a vessel from the Institution crosses it on the way to some other mission more readings are taken of its varying qualities. The stream is usually found about 200 miles east of the Massachusetts research center but the river often moves four or five miles a day from its average position and may shift as much as 100 miles in a week. Because of its habit of turning back on itself, the stream may be crossed two or even three times by a ship traveling in a straight line across the ocean.

In recent years the Gulf Stream has frequently been tracked by aircraft and by satellites which can detect it both from color photographs and by infrared meters which spot it by the warmth that it radiates. Fuglister prefers to follow it by sea because a ship can stay with it longer and does not have to wait for ideal weather. Naturally, he has a theory to explain the meanders and the rings, one with which, as he says, not everyone agrees. He believes they are caused by a combination of factors. In the order Fuglister states them, the contour of the bottom as a cause for the shifting current comes first. Since the Gulf Stream,

at least in the area he has studied most intensively, reaches all the way to the ocean floor, hills, ridges, shelves, slopes, and seamounts must all have an effect on the flow. Next he mentions the rotation of the earth. The Coriolis effect is greater as the latitude gets higher, the farther removed one is from the equator, and this differential is reflected in the stream's behavior. Lesser variations may be added by forces that are themselves far distant.

The ocean through which this quixotic stream moves, the Atlantic, has many other kinds of motion as well. (In fact, with the exception of a few places such as the lower portion of the Black Sea and the Red Sea "funny water," no water in the ocean is actually still.) It is a fact that no human being can possibly visualize or comprehend that the earth's surface contains 139 million cubic miles of sea water. This is spread over three-quarters of the globe and the average depth is about 12,000 feet. All of this water is going somewhere, in patterns only somewhat understood by the physical oceanographers but of considerable importance, if we only knew it, to everyone.

In the Atlantic the Gulf Stream has its counterpart in the Brazil Current, the water that flows down the coast of South America, driven by the Coriolis force, after the South Equatorial Current hits the continent. The Brazil Current is much shallower and weaker than the Gulf Stream, in part, perhaps, because of the strong, cold current coming north underneath it that originates in the seas of the Antarctic. The most dramatic flow in the Atlantic south of the equator is the Benguela Current. This is cold, Antarctic water that runs up the west side of Africa. Curiously, plankton, the basic food of the sea, thrive much better in cold than in warm water so this Benguela Current is rich in nutrients. Recent studies in the Gulf of Guinea, where Africa makes a sharp left turn, have shown

an abundance of sea life that, if properly harvested, should be of considerable help to that protein-poor continent. As the Benguela reaches the latitude of zero at the equator, the trade winds and the shape of Africa force the water west toward Brazil. Between the north and south equatorial currents there is a curious countercurrent that runs on the surface to the east.

Beneath these currents the Atlantic is divided into a number of temperature layers. The mystery of these layers is that they are so abrupt. The top 1,500 feet of the middle Atlantic averages in winter or summer about 65 degrees Fahrenheit. Then from 1,500 down to about 4,000 feet it changes suddenly and becomes extremely frigid. This change, called a thermocline, is not gradual. Why not? Then, between 4,000 feet and the bottom, the water is close to freezing, even at the equator. This suggests that the very deep water must come from the poles. These thermoclines, which vary, have some quite practical consequences in warfare. The speed of sound in water is five times as fast as the sound carried in the air but its speed varies according to the temperature, density, and salinity of the water. Submarines can be detected by sound gear, but if they are resting on the other side of a thermocline from a pursuer, the sounding gear may not find them and it is almost as if they were hiding in a darkened room. The U. S. Navy has spent hundreds of millions of dollars studying the speed of sound through various kinds of water.

The Navy did not realize how little it knew about the propagation of sound in the sea until shortly before the United States became engaged in World War II. Officers conducting antisubmarine exercises in the warm water off Guantanamo, Cuba, tracking their targets by sound, discovered they could not find the ships using the methods

developed in the much cooler waters off the submarine base at Groton, Connecticut. Scientists of the Woods Hole Oceanographic Institution in Massachusetts had been looking into the relationships between water of different temperatures and the Navy went to them for advice. The Navy was told its sounding gear did not work properly off Cuba because it was calibrated for water where sound had a much different velocity. The Navy immediately began a research relationship with Woods Hole and now has scientific contracts with many other scientific groups outside the federal government as well.

Years of study have shown that the behavior of sound in the sea is very complicated indeed. Water does not become colder in a straightforward manner the farther you sail away from the equator toward the poles. The temperature varies according to the seasons. In addition to the major thermoclines mentioned in connection with the great layers of the ocean currents, there are many minor thermoclines that occur and maintain themselves according to rules not presently understood. A number of thermoclines seem associated with internal waves; one reason for studying these deep water motions. Another source of thermoclines comes when two currents with different temperatures converge. (Unlike so many scientific names, this meeting of two currents has an easy label. It is called a convergence.) Tides also change the temperature of the water and so do winds.

If the military had only to account for temperature changes in forecasting the water speed of sound, their job would be difficult. This is only one factor, however. The amount of salt in the sea is also important. As the water becomes saltier, the sound's speed increases. The Gulf Stream is saltier than the ocean around it. Bodies of water with more than average evaporation, such as the Carib-

bean, the Mediterranean, and the Red Sea are considerably saltier. The sea is less salty off large rivers such as the Amazon and the Mississippi and also in the Arctic Ocean and the Baltic Sea which have numerous rivers flowing into them.

The third basic factor in sound propagation, density, which also increases speed, is not too complex since it increases in a more or less orderly manner with depth. Sound tends to reverberate with depth, however. Near the surface, waves may create a roughness in sound transmission that must be accounted for. Waves also create air bubbles to which the sonar gear reacts as if it had discovered a small target. The air bubbles come under the scientific name of cavitation, a way of saying that a liquid has local cavities.

Air, presumably, has something to do with the deep-scattering layer, the DSL, that plagues submarine hunters. Sound gear operators have often reported very suspicious contacts hundreds of feet below the surface, alerting the destroyer captains to drop depth charges on them. Some of these contacts turned out to be whales. Others were much more mysterious when proved not to be submarines. The falso echoes were blamed on the DSL, which was thoroughly studied for many years. One of the curiosities of the DSL is that it rises at night hundreds of feet closer to the surface and then begins to sink again as day breaks. This behavior led to the idea that schools of fish migrated upwards to feed on the vegetable plankton (which must live in the upper water to be near the sun) when it was dark and therefore safer. These schools of fish then presumably retreat to the darker depths when the surface begins to be light. The fish turned up as targets on the sound gear because they were species with swim-bladders containing air that reflected on the sounding impulse. A

whole school of fish with swim bladders could easily resemble a submarine.

But for many years no one was able to catch the fish at this behavior. Many kinds of fish, most often squid, were implicated as the DSL, but various kinds of nets and trawls used to catch them and prove the theory did not bring up anything conclusive. Only recently a small research submarine, *Alvin,* did what no one had been able to do before. After detecting a DSL one night, it submerged unlighted to the depth indicated on the sounding gear, waited until the intrusion would be forgotten by whatever was there, then sailed into the target, lights on, motion picture cameras working, and several nets out to catch samples. This particular DSL turned out to be composed of lantern fish. The mystery of the DSL is at least partially solved. In many or most cases it is caused by schooling fish, but there may be other agents as well and, until it can be differentiated from submarines, it will continue to fool the sound gear.

Contrary to Captain Cousteau, who titled a book *The Silent World,* the sea is a very noisy place. Many of the animals who live in it contribute to this racket. The mammals, porpoises and whales, seem to be very loquacious. Many kinds of fish and even a variety of snapping shrimp make sounds for various reasons. Most of these emanations can be picked up on sound apparatus and, even if they are not confused with a lurking enemy, can be distracting and perhaps even loud enough to drown out weak but potentially important echoes. One night off the coast of Florida, a school of porpoises were so attracted to the strobe light attached to a camera being lowered to photograph the bottom that they kept insistently swimming around it, chattering to each other. Their noise was so great that the sound gear being used to gauge the depth while

lowering the expensive instrument to the bottom could not be heard. The experiment had to be abandoned.

Animal life is not the end of troubles associated with sound in the sea. Sound channels have been found, particularly near islands, which deflect the energy from paths it would normally take. Attempts have been made to map these channels, a task that is made more difficult by the fact that they vary with the seasons.

The bottom of the sea, to add another factor, tends to have a scattering effect on sound and there is a loss when it is rough. Surveys are made of the ocean floor for "microroughness" and diagrams drawn of its "microrelief." One such picture in the Pacific used 700 photographs and showed that there were five major types of roughness, each doing something different to sound transmission. In addition, the sea floor has "random inhomogenities" though so far no one has mapped them.

According to the Oceanographer of the Navy, whose office is the source of most funds for this research, "turbidity layers are also sound scattering layers and may play a basic role in acoustic volume reverberations." For turbid, one might substitute muddy. Such water might come from a landslide in the sea, be found at the mouth of a river, or even come from dirty ice. It may change with the seasons. Turbidity layers may not be easy to forecast, but if, as the Navy assumes, the security of the United States depends on a complete understanding of the behavior of sound in the oceans, the role of turbidity will be understood.

An understanding of sound in the marine environment hardly existed in 1940. Today many mysteries seem solved, and research may be mostly concerned with getting facts and figures, making maps and graphs, rather than with performing work in pure science. In the name of national

defense, however, an abstruse knowledge has been acquired in an effort that probably has no historic parallels.

To the Navy, of course, and to Congress which voted the money, such a project, which may actually have cost several billion dollars, is worthless unless it has practical applications. The work on sound definitely has. Offensively or defensively, the U.S. fleet of nuclear submarines is in the military front line. Several of these ships have traversed the North Pole under the sea. Another, the *Triton,* has gone around the world broaching the surface only twice. An important part of their navigation was by sonic means, particularly when wedged in between the polar ice and the jagged mountains that reach up from the floor of the Arctic sea. Their ability to run silently, to hide in waters where sound is blind, to hear and identify an approaching aggressor, to put into a computer the knowledge needed by "acoustically homing torpedoes," these are just a few of the unclassified capabilities that require a knowledge of how sound works in the sea. Detection of far distant explosions and development of underwater radios that will deliver human speech hundreds of miles away are other aspects of this effort involving several thousand people. If we learn to talk with porpoises because of a Navy project studying their mode of speech, then we will also have a spin-off of considerable fascination. Another use of deep-sea knowledge of sound, seldom considered, might be its application to study of the deep currents.

The speed of currents on the ocean surface can be fairly readily measured, but deep water movements present a problem that has not yet been solved. An attempt has been made to gauge the motion by comparative salinity. The surface water is saltiest because the fresh water has evaporated. Deeper water is about one percent fresher.

The least salty water in the Atlantic comes from the Antarctic. Moving north this water sinks several thousand feet and travels at a rate of about five miles an hour up the South American coast. It cannot move up the African side of the ocean basin because the Mid-Atlantic Ridge stops its passage. Near the equator there is a break in the Ridge and some of the flow moves to the east. This particular fresh and deep stream finally disappears about 1,200 miles north of the equator.

Beneath this Antarctic mass is a layer sometimes called the "Upper Deep Water." Apparently this very salty flow comes from the Mediterranean where the rate of evaporation is very high and the inflow of fresh water not too considerable. This heavy, salty water flows out into the Atlantic at the sill of Gibraltar while, above it, Atlantic water continuously flows in. This Mediterranean water spreads all over the Atlantic and has even been detected at the Cape of Good Hope in South Africa.

Farther down, between 9,000 and 13,000 feet, there is a level with a very low oxygen content. This water evidently originates off Greenland in the latter part of the year, sinks because it is cold, and loses its oxygen because this chemical is used up in the oxidation of the various kinds of dead sea life raining down from above.

Beneath all this is another mass of Antarctic water which follows the same course as the similar mass many thousands of feet above it. None of these deep flows move rapidly enough to be measured by current meters. How long they take to complete a cycle and return to their place of origin is also not known. Certain experiments suggest that some of these deep flows originate only spasmodically and that the rhythms may change considerably. One study suggests that the cold water off Greenland may have been at the surface during the year 1812, producing

the disastrous winter during which Napoleon lost his army in Russia. Whatever causes the deep ocean flows, it is believed that the surface currents, the Gulf Stream, the Brazil, and the Benguela, have so much momentum that they would continue to flow for at least three years even if all winds stopped and the atmosphere remained dead calm.

In the Pacific Ocean, the currents have a similar pattern, though not an exact counterpart.* The Japan or Kuroshio Current moves like the Gulf Stream but has no Sargasso Sea. The Pacific has no icebergs because the Bering Strait is too shallow to allow them to pass the Aleutian Islands. There is no counterpart of the Brazil Current on the west side of the Pacific because the innumerable islands of the South Pacific break up what would otherwise be a steady flow.

The most interesting current in the Pacific is the Humboldt off the west coast of South America. (The Kuroshio is very fine and productive of fish, a great boon to Japan, but oceanographically it simply poses the same problems as the Gulf Stream.) The big flow of water off the west coast of South America first reached the literature in the writings of Alexander von Humboldt, a German who practically invented scientific exploration. Humboldt spent a number of years studying South America and, incidentally, created the guano industry which had a monopoly on the agricultural fertilizer market for many years. Guano, to the extent that it is caused by bird droppings, is a direct result of the current that Humboldt described.

The Humboldt Current and the Benguela, off Africa,

* Various studies of deep Pacific currents are being made, but the outlines of movement in that vast body of water are not yet as well known as those in the more heavily surveyed Atlantic.

are nearly exact cousins. The rotation of the earth slams the cold water originating in the Antarctic off the great continental masses. The Benguela has not been completely exploited but the fisheries in the Humboldt are the most productive in the world. (As a sidelight, the cold Humboldt apparently induced penguins to migrate in it so that a species of this cold-water bird lives in the Galapagos Islands, right on the equator.) The biggest crop in this plankton-rich water is a species of anchovy. For countless centuries birds harvested these fish and made their nests on the islands through which the current passed. Humboldt showed how their leavings could be extremely profitable.

But the Humboldt, to the sorrow of man, is not always completely dependable. Every so often something occurs which is called *El Niño.* An atmospheric disturbance of unknown origin deflects the great stream. The fish die. The birds starve. Great torrential rains fall on land that, ordinarily, is almost a desert. The rains cause floods, landslides, and general havoc. The rotting fish, killed by the disappearance of the current, make the harbors intolerable. *El Niño* has other other consequences as well.

The National Science Foundation report of 1967 commented on this.

> Recent studies have shown that changes in water mass characteristics in one part of the ocean may have a pronounced influence on oceanic and atmospheric conditions in distant areas of the earth.
>
> J. Bjerknes of the University of California at Los Angeles, recently completed an extended investigation under a grant from the Foundation of one of the greatest and most extensive oceanic anomalies, the *El Niño* conditions in the eastern Pacific Ocean equatorial regions. He showed that periodic anomalies in the equatorial easterly winds have a major in-

fluence on the atmospheric circulation in the Gulf of Alaska and in the North Atlantic and may be the cause of severe winters experienced in Europe.

El Niño conditions start with decreases of the prevailing equatorial easterlies in December. Easterly winds along the equatorial regions, due to earth rotation effects, move the water north in the Northern Hemisphere and south in the Southern Hemisphere. This results in spreading of the surface waters and subsequent upwelling of subsurface cold waters. During *El Niño* conditions, this effect is subdued, and surface temperatures are 2° to 3° C. above normal over vast areas from the Americas to the mid-Pacific.

Dr. Bjerknes showed how the Northern Hemisphere weather reacted to this increased sea temperature; stronger westerlies over the Northern Pacific, deeper low pressures in the Gulf of Alaska, consequent weather westerlies north of Iceland, and weaker lows in the Icelandic areas. A determination of the requirements of long-range climatic changes will necessitate monitoring oceanic as well as atmospheric conditions for an extended period of time.

It is clear, then, that a change in a Pacific current below the equator can affect conditions as far away as the North Atlantic, but this fact does not answer a basic question. Why does *El Niño* exist in the first place? Why do the prevailing easterlies sometimes fail? The Benguela Current, the Atlantic counterpart of the Humboldt off western Africa, also warms in certain years, causing disasters. Presumably the reasons for the warming are the same, but is this certain?

As has been said, practically all the water in the ocean is in some kind of motion. The results of this are often quite obvious. The cool current off California, the last gasp of the Japan Current, keeps that coast tolerably comfortable during what would otherwise be miserably hot summers. The Indian Ocean has two major currents cre-

ated by the monsoon winds, which bring the rains to India during the season. The regions where these currents flow may, as the result of recent research, turn out to be major fishing areas. The Agulhas Current, which pours against eastern Africa in the same way that the Brazil Current flows against South America, may also prove to be an excellent region for fishing. The vast current that runs unobstructed round and round the bottom of the world, known as the Antarctic Convergence, is loaded with plankton on which the whales used to thrive and is still a rich pasture for many kinds of life. Naming these various flows, however, does not give a complete catalog of the motions of the sea. In 1958 a stream was found in the Pacific known as the Cromwell or Equatorial Undercurrent that flows quite rapidly, about 100 or 200 feet beneath the surface, from west to east. No one had suspected its existence but once it had been discovered, studies were made to find the same phenomenon in the Atlantic. The tests showed that that ocean has the same undercurrent. It has also been looked for in the third ocean, the Indian, but with indifferent success. Theories have been published to explain these newly-found currents, but a complete explanation is still being looked for.

Deep-sea observations and photographs show that other water motions still need to be named. Bruce Heezen, a prominent geophysicist, claims that the tops of all seamounts so far photographed showed ripple marks. When Jacques Piccard and Lieutenant Don Walsh descended seven miles in the *Trieste* they found forms of life even at the bottom of the Marianas Trench, demonstrating that oxygen had arrived there somehow and must have been transported by moving water. A great number of deep-sea cores have shown very little or no sediment on bottoms where it should have existed. The probability is that these

areas have been kept clean by eroding water. Satisfactory instruments for measuring deep-sea currents have not yet been developed, but the evidence for continuous movement in the abyss is nevertheless quite strong.

One curious kind of motion in the sea has been given the name of turbidity currents. These currents are curious because, although their existence was first suggested in 1950, nobody has ever seen one. Apparently, they are quite similar to landslides. Sediment piles up on a continental slope or the head of an undersea canyon and then, triggered by a storm, an earthquake, or the mere accumulation of weight, suddenly begins to slide. Bruce Heezen and Maurice Ewing of Lamont-Doherty published a report in 1952 about submarine cable breaks that had occurred on the Grand Banks of Newfoundland in 1929. They believed that the cables were smashed by a deep-sea landslide. They calculated the speed of the flow by the times when cable service was interrupted, coming up with an avalanche moving so rapidly that other scientists expressed disbelief.

The idea of turbidity currents has been used to explain the long, deep canyons that appear on the edge of continental shelves. The thought is that the landslides have scoured out these large features. Again, there is no direct evidence to go by, and the currents as the explanation for canyons can only be accepted on faith. One thing about them seems certain. They are an important source for the matter on the ocean's abyssal floors where the sediment is unusually thick.

Another kind of action in the sea is created by internal waves. Internal waves have no direct connection with the waves on the ocean surface but their presence below can be detected when, far out in deep water, the ocean begins to bubble and froth as though it were striking a sub-

merged reef. Some of these internal waves, though they cannot be seen, have been measured by their temperature and turn out to be as much as 300 feet thick, many times larger than any wave a sailor will ever see from the deck of a ship.

These great waves that rise and fall invisible to us seem to be caused by discontinuities between water of different temperatures or salinities. Some scientists believe they derive their initial stimulus from storms that may be thousands of miles away. Others think they may be caused by earthquakes in the sea.

They seem abstract, perhaps, but there is an easy method for visualizing them. If you fill a glass bowl half full of salt water and a little dye, then add fresh water on top of it, a little paddling of the colored water with a spoon will produce a small-scale internal wave.

Although the causes of internal waves have not yet been discovered, studies on their effects are being made. It is seriously thought that the U.S. nuclear submarine, *Thresher,* which sank without explanation in 8,000 feet of water off the New England coast, may have been the victim of an internal wave. Possibly the ship became trapped in some tremendous downsurge at a moment when the equipment to handle such matters was not functioning properly. There is also speculation about what these waves may do to the animals in the sea. Many of them are adjusted to very delicate balances of temperature and salinity. What becomes of them if they are suddenly caught by some wave with water of a character to which they cannot adjust? This is not an easy matter to study, but an understanding would be very helpful for knowing the conditions of life in the sea.

Another great motion in the sea comes from the tides caused once or twice a day by the moon and the sun. For

practical purposes mostly connected with maritime activity, the tides at the principal harbors of the world have been studied for many years and their behavior can be predicted with all complete and necessary accuracy. What interests scientists now is what the tides are, and their effect, in the deep sea. To determine this, dependable deep-sea gauges are needed; these are in the process of development at the moment. This study is still in its infancy and so predictions about what the researchers may learn remains, for the moment, still quite general. One specific result may be an understanding of how deep tides affect internal waves. These tides also affect the earth's magnetism and gravity and the gradually slowing rate of its rotation. The instruments developed to study deep tides may also be used to measure the flow of heat from the interior. In a paper on this recondite subject, Walter H. Mynk and Bernard D. Zetler wrote, ". . . the proposed program has applications in much of Earth's environment, air-sea dynamics, various ocean-wave phenomena, and the anelasticity [rigidity] and stress fields of the solid Earth. The bottom of the sea is perhaps the least explored of the 'accessible boundary layers' on this planet, and we may be in for some surprises." *

The sea in perpetual motion is a stern subject, one of the most challenging in all the complexity of nature around us. We can only see bits and pieces of it. What happens beneath the waves may seem remote and unimportant, but that subject of more direct, personal concern, the weather, can never be mastered until the sea which controls it is understood.

* *Science,* 158 (November 17, 1967), 884-886.

XI.

Unusual Weather

WHEREVER I go," said the anonymous traveler, "the weather is always unusual."

When the early movie makers of New York City, Astoria, and Fort Lee, New Jersey, took their cameras west to Hollywood, California, to photograph in the land of perpetual sun, they publicized a half-truth into a national myth. Southern California had a pleasant atmosphere but, if it had ever been a clear-skyed Garden of Eden, the millions of people attracted by its fables have planlessly changed the Los Angeles area into a meteorological slum.

The forces of nature seemed very kind to the Golden State. Enormous wealth in minerals, beautiful mountains, spectacular redwoods, rich though arid farmlands, great fishing in the sea, two great harbors, San Francisco and San Diego, fine weather at selected locations: here was a land where a man could grow rich and content. But "the Lord gave and hath taken away," particularly from men who failed to realize that the forces of sea, land, and sky are much more powerful than men can ever hope to be.

Men tapped the Colorado River in 1901 to irrigate the Imperial Valley, then a desert, but the canal overflowed

when no flash flood was expected, and the river created the still-existing Salton Sea before it could be tamed again. Men built the proud city of San Francisco on an earthquake fault that nearly destroyed it. They built another city, a vast one, on a great plain to the south, open to the sea on the windward side but otherwise surrounded by mountains. The new settlers on the Los Angeles plain found great pools of water under the ground that the Spanish had never drilled and they brought this to the surface to raise cattle and oranges. When they had exhausted all this water and the wells ran dry, they raided the Owens River Valley, with guns, the Colorado, with dollars, and now finally are bringing water in from 400 miles to the north. They built houses high in the hills, paying little attention to the facts of erosion. Many forest fires, new roads, and housing developments have taken away much ground cover. Now the winter rains destroy houses and lives in mud and landslides. They built high apartments on the big bluff along the coast highway. Parts of the bluff collapsed and closed the highway. Now a causeway is planned that will carry the highway out to sea, away from the bluff. This may destroy the Santa Monica beach, and will certainly upset the fishing, but builders never care. Offshore, men fished the sardines so heavily that, when the temperature of the water changed for a time, the sardines could not survive in sufficient number to come back later and now the anchovies have taken over. Steinbeck's *Cannery Row* is dead.

Probably no one could have foreseen the disaster that would be caused by the introduction of the automobile to Los Angeles County. No place in the world seemed better suited to driving. Here was the ideal country for a convertible with the top down, dashing up into the mountains, down to the beach, off to the Valley, the races,

or Tiajuana. Roads grew like weeds to accommodate the cars. Even the poorest inhabitant owned some kind of gasoline-burning vehicle. Pierce Arrow or Tin Lizzie, Mercedes or hot rod, they all spilled exhaust fumes. A million cars on the road every day, running around in a bowl from which the air often could not escape.

Los Angeles faces west to the sea and pleasant breezes usually blow in fresh from the Pacific. Ordinarily the winds can blow across the wide plain and rise when they hit the mountains. Sometimes, however, there is a condition called a temperature inversion. In this situation the upper air, instead of being normally cooler, is warmer than the air near the earth's surface and the lower air cannot rise and get over the encircling mountain ranges. When this happens, all the gasoline exhaust, plus the many other fumes of the city, load the air to create an acrid condition of low visibility and high tear content known as smog. (What creates an inversion is not completely understood.) Other cities have also had smogs but none so notorious as those which plague this sunny city on the Pacific. Many movie stars who helped make Hollywood famous have fled Los Angeles County to get away from the smog.

California presents a very dramatic object lesson in the importance of nature in human affairs. Of all nature's activities, weather is the most obvious. Large cities may be unnatural in many respects but none of them can escape the weather's effects. It reminds us of itself every day. We hear the weather reports on the radio and choose our morning costume in a compromise between the forecast, what we see out the window, and what our planned activities may require.

What makes one day's weather differ from another's? The great differences in the seasons seem obvious enough.

Winter is cold because the sun has gone south. The sun shines for less of the day and even then it is low on the horizon. In summer the sun has come back to provide long days during which it is more nearly overhead. But why is one day cloudy, another full of sun, why tornadoes, hurricanes, hail, high winds, and all the other events in the weather bag of tricks? Although short forecasts can be made because, in a general way, the ordinary motion of weather from one place to another is known, the basic scientific reasons for the various phenomena are hardly understood at all. A vast amount of research work is being done in many places so that the extremely complex interaction of the many forces that create weather may be reduced to formulas. Then, one day, with the aid of computers many times faster than any existing now, we will have truly long-range forecasts of great accuracy. Thus it may be possible to say that if it is clear in Anchorage today but raining in New Orleans, then Montreal will get snow on Wednesday and London will be unseasonably warm.

In New York City, Boston, or Washington we seldom think that the choice between raincoats, overcoats, or no coat is often determined over a stretch of sea three or four thousand miles out in the Pacific west of Los Angeles. Recent studies suggest this may be at least part of the case. One enthusiast has called this ocean area "the birthplace of American weather." The idea that the rain on our windowpane is falling because of events half-way round the world is a large one to accept. But, of course, the rain had to be caused *somewhere*. The fact to grasp is that all the weather in the world belongs to the same system. We all live under one umbrella.

The idea that events far out in the Pacific have a very direct effect not only on the West Coast but all North

America arose from the attempt to explain some quite abnormal conditions that have occurred in the atmosphere. During the 1930s a severe drought struck a great part of the United States between the Rockies and the Mississippi. It seemed all the worse for farmers already suffering from the severe financial depression of the time. The drought created what became known as the "Dust Bowl," and clouds of topsoil from the farms were carried by the prevailing west winds all the way to the states on the Atlantic coast. In 1953 another disastrous dry period came to the southwestern United States, in particular to Texas. For four years during the 1960s the northeast United States had so little rainfall that it seemed for a while as if the reservoirs of New York City, one of the largest water systems in the country, might run absolutely dry. At the same time usually dry parts of the country were getting heavy rains.

What made these things happen? Can they be predicted? One answer is being sought to the west, where the winds come from. Scripps Institution of Oceanography of the University of California, with the backing of the Office of Naval Research, is doing a long-term study on the project.

It is known that "strongly abnormal" temperatures of the surface water often occur in an area north of the Hawaiian Islands, a rectangle about one-fifth the width of the entire Pacific and about 500 or 600 miles from north or south. These abnormal temperatures last for long periods of time in this large part of the sea. They create changes in the speed of sound in water, changes in ocean and air circulation, in the migration of fish, and unusual weather over the North Pacific, the United States, and possibly all the northern hemisphere.

It is also known that the sea-surface temperature is

abnormal more often than not. Sometimes the width of the area may grow to one-third or one-half of the whole Northern Pacific. The changes last for at least three months and some have gone on for as long as 30 months. They travel from west to east at about 200 miles a month and often do so for two or three years. When the abnormality is a cold one, it will be seldom more than 3.5 degrees different from normal, but a warm abnormality may be as much as 12 degrees above the average.

Ever since records have been kept in the lands around the Pacific, the weather has fluctuated almost continuously. These fluctuations were thought to be merely local until recently, when comparisons showed the fluctuations to be the same over distances of hundreds of miles. Sometimes departures from the norm turned out to be the same in places as far apart as California, Peru, and Japan. If the readings at such times were not the same number of degrees above or below normal, then the difference between one reading and another would depart the same amount from normal, but on opposite sides of the line. Thus, if a station in California reported 3 degrees above, a station in Peru might report 3 degrees below. In 1958 a mass of warm surface water approached the west coast of North America. This seemed to cause an unusual wind from the south. The California Current, which ordinarily flows from north to south along the coast, moved out to sea and warm subtropical water from the Central Pacific flowed up the shore as far as British Columbia.

In hopes of establishing some kind of pattern, scientists are studying all available evidence of Pacific coast weather in the past. They are looking at rainfall records from Spanish missions, whalers' logs, logs of Spanish galleons, and documents left by American pioneers. Information about floods, about rare snowfalls in southern California

and Mexico, unusual migrations of animals, and the appearance of rare plant species will help provide a history of weather in the past. Records of some little-known Spanish expeditions in the Pacific in the eighteenth century are also being studied. Men are unearthing the kitchen middens of ancient Indians (their refuse heaps) for evidence of the kind of plants and animals they consumed.

In certain coastal areas, from Canada to South America, sediments have been laid down in varves, layers of light and dark clay. The light strips indicate summer deposition, the dark stripes materials that have fallen to the bottom in winter. Sediments like this can only accumulate where neither current nor bottom animals make a disturbance. They are just like the annual growth rings in a tree. The fossil shells in the varve can be typed as to cold and warm water species and this should give an idea of past temperatures at the various locations.

Though useful, all this does not seem sufficient to the scientists. They want more accurate, broader, simultaneous observations. At present only sea surface temperatures are measured simultaneously at many places. What is desired is knowledge of what happens beneath the surface during fluctuations, plus information about the difference between day and night temperatures, the wind, humidity, and other atmospheric conditions.

To do this Scripps and the Navy are setting up a number of unmanned buoys in very deep water, usually between 12,000 and 18,000 feet. These buoys will remain for a year or longer, taking measurements of many different elements changing in the sea and the atmosphere. The Navy buoys store the information on tape which on command radios the data to a shore station. The information in the Scripps buoys is recorded photographically and

picked up at intervals by a Coast Guard cutter. Scripps has called its sensors "bumblebees" in deference to their looks.

John D. Isaacs of Scripps, principal investigator in this study, finds that there are two most interesting questions to be answered. Are these great masses of unusual surface water created entirely by wind transport, or do they come from some kind of feedback mechanism in which abnormal weather and abnormal water temperature reinforce each other? This is a variation on the problem of the chicken and the egg. Which came first? Does the water change the atmosphere or is it the other way around, or is the whole system more complex than that? The other question has been phrased "What large-scale initial instabilities or oscillations of the ocean appear to occur in the North Pacific?" For purposes of prediction, it is important to know what makes the abnormalities begin.

There seems no question today that changes in ocean conditions affect the lives of vast numbers of people. The disasters that come to Peru when *El Niño* changes the Humboldt Current have already been mentioned. The droughts and occasional California floods have also been cited. Most dramatic of all, of course, are the hurricanes that spawn in the southern seas and terrify the Caribbean islands, and the U.S. Gulf and East coasts, as they pursue their erratic courses.

Numerous mysteries of meteorology are included in the general study known as "air-sea interaction." The phrase is not very descriptive and needs explanation. According to the Environmental Science Services Administration, which includes the Weather Bureau, "The mechanism of sea-air interaction is almost unknown, yet it is the primary process which drives the atmosphere's circulation and its weather systems. Unless this process

is explored and understood it will be impossible to extend weather prediction to more than a few days."

In *Physics of the Marine Atmosphere,* H. V. Roll describes the study as what the sea surface does to the atmosphere, how water, the radiation of the sun, elements of chemistry, electricity, radioactivity, and biology are exchanged between ocean and air. Many phenomena that occur over the sea do not occur on land. Owing to the vastness, the enormous energy involved, and the variety of forces at work, the studies must be done at sea, but this is difficult because a fixed position is so hard to maintain. "A full understanding of the interaction of ocean and atmosphere can only be approached if the exchange of momentum, energy, and matter between these two vast energy reservoirs is discussed with a view to its bearing on the pattern of atmospheric circulation, its instabilities, and fluctuations." When Roll wrote, in 1965, he declared, "Climatological radiation data taken close to the sea surface are almost entirely lacking."

Another description of the problems was made by Joanne B. Malkus in a book called *The Sea.* She explained that winds get their power from the sun, but only with the sea acting as intermediary. The trade winds pick up water vapor, which has the heat of the sun in it. Giant salt particles collect the water into raindrops, which fall, leaving the released heat in the air. Hot air flows naturally from the tropical areas toward the cold areas to the north and south. Near the water surface rough waves act as a brake on the wind but these waves are "the main transporters of the globe's huge ocean currents." There are numerous small feedbacks in these processes which possibly have large consequences. Joanne Malkus sees two basic puzzles. One is the coexistence of so many interacting

scales of motion, large and small. The other is the streakiness of the motion in both sea and air.

Obviously all this complexity cannot be reduced to formulas in a laboratory. Acting on the presumption that much North American weather originates in the tropics, large-scale research by U.S. agencies has been undertaken in those areas. The Line Islands experiment took place in 1967. The Line Islands are Christmas, Fanning, and Palmyra islands which lie in the Central Pacific just slightly north of the equator. A large series of land, sea, and air observations were made by nine different academic institutions as well as by various U.S. government agencies. Even before complete results were published it was concluded that instruments designed for weather study in mid-latitudes are not delicate enough for the subtle changes in the tropics. It was also indicated that this area does not contribute much to the general circulation of the atmosphere.

It is known beyond question, however, that the equatorial Atlantic has large-scale effects on North American climate, so another, extremely ambitious, program was undertaken to be called the Barbados Oceanographic and Meteorological Experiment, usually referred to as BOMEX. It is a step forward in the program for accurate long-range forecasting to be developed by the United States, working with many other nations, to be called the World Weather Watch. To complete a successful system, three goals must be achieved: One is an adequate worldwide observation system. At present only 10 percent of the earth is adequately covered. The second is understanding the physics involved in weather so that all the factors involved can be included in a single mathematical model. The third is to develop computers capable of processing the vast amounts of information a complete

coverage of the world would produce. An estimate is that, with complete coverage, present-day machines would take 25 days to produce a single forecast.

BOMEX concentrated on the second objective, an understanding of the complex and continuous exchange of energy, water, gases, and salt and biological particles. These processes take place most rapidly in the tropics, where the sun is strongest, and where it is believed even small changes may produce large-scale results.

The site of the project was an area of the sea about 300 miles square east of the West Indies island of Barbados. It was chosen as being typical of a low-latitude, trade-wind region but one also reasonably convenient for support from the United States. The months of May, June, and July, 1969, were chosen; July because 14 tropical storms have passed through that area, during the month, since 1901, and understanding how such storms are born was a major objective of the study.

BOMEX had the complexity of a large amphibious operation. The Departments of Commerce, Defense, Interior, and Transportation were involved as were the Atomic Energy Commission and National Science Foundation. Ten U. S. government ships, seven satellites, a fleet of airplanes, a curious craft called FLIP, and a number of fixed buoys to collect information were also engaged. Nineteen universities, including major oceanographic institutions, and six private companies also participated.

The function of so much equipment, stationed or traveling in the BOMEX square, was to get information about what was happening in various places at the same time. Scientists call this synoptic information. Only with simultaneous information could a meaningful picture be drawn of how the very numerous forces interact. Over 80 separate projects were included and readings were taken

from the sea floor 18,000 feet down to 100,000 feet above the ocean surface. The area covered was 90,000 square miles. Beyond the conventional observations of temperatures, salinities, winds, cloud cover, speed and direction of currents, and similar matters, the special projects were very sophisticated, highly technical, and it will take a great deal of time and work before they are digested separately and then assembled into one total view. Even before the results are in, the BOMEX project seems an impressive effort in man's attempt to understand his world. At the least it should give new insights into the nature of hurricanes.

The Taino tribe of West Indians who once lived on the islands of the Greater Antilles and the Bahamas knew an evil spirit they named *huracan.* When, toward evening, the sky was covered with high, thin clouds and the sun sank in a great crimson blaze, when the wind was calm and the surf boomed in long, low swells, and a little later when the wind began to blow in gusts from the northeast, the Tainos knew trouble brewed in the sea and that by morning *huracan* would arrive. These weather signs were the only warning the Indians had, but they sufficed. When the Spaniards came they exterminated the Tainos but kept their name for the storm.

What are known as hurricanes when they sweep north out of the equatorial Atlantic are known as typhoons in the western Pacific, cyclones in India, and willy-willies in Australia. Under any name they are all alike, yet quite individual. They begin in warm, tropical seas all over the earth, except in the South Atlantic. (Their absence in this water is one of the curious things about hurricanes but may be because the water is too cold since it is exposed to outflows from the Antarctic.)

They are the greatest storms on earth. With good

reason, no other manifestation of weather is so feared. The loss of life in historical times in India and in China has been awesome. Tropical storms in the Pacific are more frequent than in the Atlantic and more intense because there is a broader sweep of water over which they can pick up energy.* Atlantic hurricanes occur on an average of ten times a year and about six of them strike land, either the Caribbean islands, Mexico, or the United States; one hurricane struck all three places. Since 1900 about 13,500 people have been killed by hurricanes, but better warning systems have sharply reduced the loss of life in recent years. Losses of property, due to the population increase and more development of coastal areas, have increased, however. Betsy, in 1965, cost $1.4 billion.

The most experienced hurricane watcher has trouble predicting the course a great storm may take. For the United States, Texas and Louisiana seemed the chief victims. A storm in 1900 hit Galveston and took 6,000 lives. The Northeastern states seemed immune. Hardly anyone living in the 1930s in the area remembered one of the big blows, the last on record in the area having occurred in 1869. Then in 1938 an immense hurricane struck New York and New England with enormous destructive effect because the warning system hardly existed and the residents had no experience, as the Caribbean Indians had, in recognizing the telltale signs. Since that time a number of hurricanes have hit the United States' Northeast, and the residents have become more wary. Nevertheless, Hurricane Diane of 1955, which caused little wind damage, brought floods to Pennsylvania, New York, and New England that killed 200 people and caused about

* The U.S. West Coast is seldom hit by hurricanes because the cool, southbound current usually deprives the storm of its energy.

$700 million in damage. No one knows why this area, so long considered safe, has become a prime target. What is known is that storms forming early in the season, between June and August, start in the Gulf of Mexico, and, if they are to reach the Northeast, must cross a considerable amount of land which will decrease their strength. September to November storms form in the Atlantic, usually, coming in from the sea to hit the Northeast in full force. The very last storms of the season are likely to come once more from the Gulf. The pattern remains unexplained. At this point it might be asked why there is a "hurricane season." The best, though not yet completely scientific, answer is that during the season the trade winds are much weaker, setting up part of the complex set of conditions necessary to their formation.

Once the conditions are explained under which it is known they can happen, the problem is not only why they happen but "Why are there so few of them?" Some of the major, basic conditions for hurricane formation, the intense heat at the equator, the great amount of moisture evaporation, the moving winds are in existence together most of the time. Why don't hurricanes happen every day?

The more one studies hurricanes, the more difficult they are to understand. What happens after they form, however, seems fairly clear. In the mid-Atlantic during summer months, the dominant pattern is the Azores-Bermuda High, a fairly stationary region of pleasant weather. North of this the prevailing winds flow to the east, from the surface to altitudes of 40,000 feet or more. South of the Bermuda-Azores High, the trade winds flow to the west and in summer deepen to altitudes of 40,000 feet or more and spread out over the tropics.

Sometimes the Azores-Bermuda High becomes weak

and drifts south of its normal position and the trade winds become shallow. When this happens the normally eastbound winds to the north may move south and penetrate the tropics. If this intruding air becomes trapped and there is a convergence of air of differing temperatures and directions, a hurricane may develop. Sometimes what is called the "easterly wave" may appear. In this condition the west-moving trades become embedded in the east-moving winds. There are alternate areas of converging and diverging airflow. All is well as long as the air diverges. When the two opposing forces converge, the surface winds that have been picking up heat-laden moisture from the sea increase and heavy clouds form to heights of 30,000 or 40,000 feet. This may prove entirely harmless and create nothing but rainstorms. Or, triggered by still unknown forces, a hurricane may develop.

Quotations from a booklet called "Hurricanes" put out by the Weather Bureau show the extent of the problem:

There is still no exact understanding of the triggering mechanism involved in hurricane generation, the balance of conditions needed to generate hurricane circulation, and the relationships between large and small-scale atmospheric processes.

The view of hurricanes as atmospheric engines is necessarily a general one. The exact role of each contributor is not completely understood. The engine seems to be both inefficient and unreliable; a myriad of delicate conditions must be satisfied for the atmosphere to produce a hurricane. Their relative infrequency indicates that many a potentially healthy hurricane ends early as a misfiring dud of a disturbance, somewhere over the sea.

A method of predicting progress of the tropical cyclone (called a steering current) by marking a warm tongue of moist

air which may extend more than 1,000 miles ahead has been devised. No theory has been found to explain this steering current yet.

Relatively the tropical meteorologist has a much more difficult problem. He deals with air masses in which there are few temperature contrasts horizontally. Disturbances here are first evidenced on a much smaller scale. Small depressions or vortices can easily be lost in the vast ocean reaches where ships and planes are the only observers and yet they can quickly grow into major tropical storms.

Hurricanes are so little understood that, while one authority states that one day's released energy, converted into electricity, would supply the United States' electrical needs for more than six months, at about the same time another authority writes that a hurricane may pack energies up to 100 to 300 times the electrical energy produced in the United States in a year. How can such figures be obtained? The storms are too vast for accurate observation and it was once thought too dangerous to venture anywhere near them at sea. Ships caught accidentally have ridden them out, but the ordeal was never of the Captain's choosing.

Then on July 27, 1943, Major Joseph P. Duckworth of the Army Air Corps flew a single-engine trainer into a hurricane off Galveston twice in the same day. The first man to dare such a thing, he lived to dine out on his exploit. Hurricane reconnaissance began as a formal program of the U.S. government in 1944 and has continued ever since. Its object is not scientific but to act as an early warning system and, once a major storm has developed, to track its course. Lives and planes have been lost in this deadly pursuit, even with better and better planes and more sophisticated equipment. Often the aircraft flies right through the winds swirling at 100 or

more miles an hour, with rain so thick that visibility is zero, until it penetrates to the eye of the storm, the dead center 20 or 30 miles across, where the sun may be shining, the wind still, and the sea visible five to eight miles below. While in the eye, many tests may be taken in the air-borne laboratories in complete comfort but, when the fuel begins to run low, the aircraft must penetrate the terrible winds and rain again to find safety on land.

Hurricanes are tracked not only by aircraft but by radar and satellites. The radar at the National Hurricane Center at Miami can detect a hurricane and locate its eye even though the storm may be several hundreds of miles away. Satellites relay pictures of cloud cover almost instantaneously to the ground where they can be studied to detect the swirling motion that is the signature of the hurricane. Satellites have often discovered potentially dangerous disturbances a day or more before there was any other evidence of their existence. This extensive early warning system greatly benefits the human race and its property, but scientists want to go farther. They want to modify the greatest storms on earth, somehow render them harmless to mankind. (Though one expert has warned that stopping hurricanes from reaching the eastern portion of the United States would have drastic effects on the area's water budget. While hurricane rains cause floods, they also fill up reservoirs and the vast underground system called the water table.)

"To stop hurricanes," said Dr. Thomas Austin of the National Oceanographic Data Center in Washington, D. C., "all you have to do is pour 1,000 gallons of skim milk on any suspicious looking spot in the sea." While Dr. Austin may not have been entirely serious about the practical possibility of doing this, he was making a very

serious point about hurricanes. This coating of skim milk between the ocean surface and the atmosphere would prevent the interchange of heat-laden water particles from the sea to the air. This process, ordinarily called evaporation, is the means by which the thermal energy of the sun, through the medium of the sea, is transferred to the winds. The cost of keeping skim milk tankers, an entire fleet of them, alert and afloat over the millions of square miles where hurricanes may breed makes it unlikely that Dr. Austin's suggestion will ever be carried out.

The Environmental Science Services Administration (ESSA) and its subsidiary, the Weather Bureau, along with the Department of Defense, have another idea about understanding and perhaps controlling hurricanes. These branches of the federal government call their idea Project Stormfury. Hurricanes draw their energy from the transfer of heat in moving masses of matter that overturn the atmosphere. Physicists call this heat-moving process convection. In a hurricane, warm, moist air spirals over the tropical seas toward the center of the storm, then the air flows upwards in a band of clouds ringing the calm eye.

The air that flows in, already turning slowly because of the earth's rotation, gathers speed as it draws toward the storm center and produces winds of destructive violence before moving upward and away from the center of the storm. The clouds around the hurricane's eye resemble a sort of chimney in which the heat rises.

Project Stormfury has for its major target the heat content of the spiraling hurricane. Tiny crystals of silver iodide, which resemble ice crystals, have been used for some years in rain-making experiments. The silver iodide is supposed to make moist air condense and fall as rain-

drops and there is some evidence that this has worked. Seeding the hot chimney of a hurricane with silver iodide might release some of the latent heat in the moist air and redistribute the storm's energy so that the delicate system is thrown off balance and collapses.

The first tests of the idea were on Hurricane Esther in 1961 and Beulah in 1963. According to the ESSA report, "The seeded portion of Esther's eyewall faded from a radarscope that detects water droplets, indicating either a change of liquid water to ice crystals or the replacement of large droplets by much smaller ones. Soon after Beulah was seeded, the central pressure of the eye rose and the area of maximum winds moved away from the storm center."

Scientists concluded, however, that the samples were too small to claim any positive success. They have understandably been very cautious about hurricane seeding because, if it seemed that their efforts had driven to the mainland a storm that might otherwise have died at sea, their scientific careers would be over and experiments with hurricanes never dared again.

They became daring enough, though, in 1968 to extend the area in which seeding would be permitted from just the southwestern Atlantic to include the Caribbean and Gulf of Mexico. They felt safe in doing this because hurricane forecasts have become increasingly accurate. The rule now is that any such storm is eligible for experiment if the chance is ten percent or less that it will come within 50 miles of an inhabited area within the following 24 hours.

It has been said that hurricanes are notoriously perverse. In 1968, for instance, many more could have been tried out for seeding but the only storm of consequence of the season came in June while the assigned aircraft

were performing other weather duties around the world. After the aircraft were in position in August to attack any suitable storm, no major disturbances occurred for the following three months. Instant science seldom, if ever, exists. Patience is a necessary research virtue. Stormfury will probably continue over the years until the question of seeding hurricanes has been settled one way or the other.

For obvious geographical reasons, the Institute of Marine Sciences, part of the University of Miami, supports research into hurricane behavior with a view to eventual modification of the storms that have struck that exposed Florida city so many times. Dr. Göte Ostlund, who teaches geochemistry and atmospheric chemistry as a professor there, has had the original idea of turning the hydrogen bomb tests made by the United States and Russia in 1961 to 1962 to research advantage. The explosion of the hydrogen bombs released quantities of tritium, a mildly radioactive isotope of hydrogen, into the stratosphere. Tritium hardly appears on the earth naturally.

Over the years tritium has slowly descended toward earth and there is now a detectable amount in the atmosphere. The sea contains much less of this isotope than the air. Beginning with Hurricane Hilda in 1964, Dr. Ostlund proposed to find out how much sea water, evaporated into the clouds and rain of a tropical storm, diluted the tritium content of the air. A measure of this dilution, he believed, would show the extent of the air-sea interchange during a storm and the importance of rapidly evaporated water as fuel for the storm.

For four years, using specially equipped ESSA airplanes, Dr. Ostlund and his associates flew into hurricanes on flights that averaged 13 exhausting hours, finally logging hundreds of hours collecting moisture samples of the

air. Laboratory analysis has shown that the amount of tritium in the atmosphere within the storm was dramatically reduced. Obviously the hurricanes, as they move along, absorb great amounts of sea water and this sea water, as it condenses and falls as rain, releases the heat into the air that gives the storms much of their energy. The possibility of controlling hurricanes by interfering with the air-sea interchange leads researchers on in the search for new ideas.* (The tritium released by the hydrogen bomb experiments has been pretty well dissipated now, so the scientists are considering new chemicals to inject into the cloud systems to calculate air and water movement.)

Weather modification, which began with just rainmaking (ambitious enough!) has expanded now not only to experiments with hurricanes but to attempts to control fog and hail. Cloud seeding to make rain began in November, 1946, when Vincent J. Schaefer dropped dry ice into a supercooled cloud over the Berkshire Mountains in Massachusetts. He seemed to produce rain, as did a similar experiment in Oregon not much later. Cloud seeding continues, particularly over the western slopes of the Rocky Mountains where researchers hope to produce more rain that will flow in streams to the Colorado River. The problem remains that no one is yet sure whether his experiment caused rain or whether it would have rained in any case. Many different kinds of stunts are being tried in hopes of learning a way to dispel fog, particularly around airports. To prevent hail (which produces about $300 million in crop damage every year), using a technique developed by the Russians, experiment-

* Dr. Austin's skim milk suggestion may be fanciful but it is illustrative.

ers are launching small rockets, full of silver iodide, from aircraft into the kind of supercooled cumulus clouds that produce hail. These rockets explode in the clouds, converting the cold droplets into snow, interrupting the transformation of the water into hail. This snow-fall melts and reaches the earth as rain.

Such practical, empirical kind of work, of course, may produce techniques of lasting benefit. It seems more likely, however, that the important results will come only when the basic problems are solved. For example, how do storms develop, how is rain produced, what creates lightning, how does hail take shape, what makes hurricanes and tornadoes grow? In spite of all that has been done, these questions do not yet have firm answers.

Thunderstorms are products of an imbalance between hot and cold, thunder and lightning an imbalance between positive and negative charges of electricity. Early in their lives, residents of the United States and Canada east of the Rockies learn to expect them after any hot day in the summer. Office workers who left their homes on a nice morning without raincoat or umbrella often find themselves besieged during July or August by a torrential downfall just as they get out from work around five o'clock. During the day the hot sun has been beating down on the earth, exciting all available water molecules upward in rapid evaporation. During the working hours the air becomes more and more saturated with moisture. At the same time a mass of cool air may be flowing one or two miles above the earth. When circumstances are just right, usually in the late afternoon, the rising, humid air reaches the band of cooler air and explosively condenses into rain. Sometimes this also creates thunder and lightning. At other times it does not. What makes the difference?

It has been 200 years since Ben Franklin showed with his celebrated kite and key experiment that lightning is nothing more than an electric spark. Though there has been endless theorizing since Franklin's day, a firm theory about how the electricity got there and what sets off the reaction has not yet been universally accepted. Nor is it understood how the atmosphere remains positively charged most of the time. This positive charge leaks to the ground so rapidly that within an hour the atmosphere should be exhausted. The fact is that the atmosphere maintains its positive charge at all times. How is this accomplished?

When a rainstorm develops rapidly the clouds become positively charged at the top and negatively charged beneath them. According to the British physicist, C. T. R. Wilson, this is caused by the difference in the falling speed of large and small drops. For some reason the larger drops are negatively charged while the very small drops have a positive charge. The difference between the positive and negative, the attraction between them, is so great that lightning, the spark, must occur. On impact, the positive charge moves upwards, recharging the atmosphere. An average of 1,000 thunderstorms occur somewhere on the earth every day and this keeps the budget constant against the continual downward leakage. (Concepts in electrical physics are difficult to understand because the subject seems so invisible and abstract. Still, there is nothing in visible about a bolt of lightning or a spark. These phe nomena are simply the explosive movements of electrical energy from one point to another.)

The higher the cloud, the more probable lightning is to occur, because the positive and negative imbalance is greater. The earth itself is positively charged and lightning strikes the highest points since they are the nearest

objects on which to complete a circuit. The thunder which accompanies lightning is described as the sound wave generated all along the column of air in which the electrical discharge occurs. In time, one may hope, scientists will understand all these events so clearly that they can be put in layman's terms and a father can quite easily explain them to his inquiring little boy. Meanwhile, one might quote George Gamow, one of the world's most lucid science writers. "But all these phenomena are so complicated that there are just as many different opinions about them as there are scientists studying them." * And, meanwhile, never seek shelter under a tree if you are caught by a thunderstorm on a golf course. Simply lie down on the grass. This procedure is not dignified but it is safe. Lightning kills more people every year than hurricanes and tornadoes combined.

Of all kinds of unusual weather, tornadoes must be the most terrifying. Though brief (sometimes they last only a minute or two), they destroy absolutely everything in their paths. Houses explode in the vacuum of their eye. Barns, cars, animals, trees, and people are caught up and flung thousands of feet, or even miles, away as these most violent of storms twist at speeds that may reach 600 or 700 miles an hour. No instrument has been able to clock them.

Accompanied by thunderstorms, they arrive with a roar like a hundred jets, black with debris and surrounded by green lightning and clouds of eerie greens and yellows. Usually they are funnel-shaped and not very broad. Their destruction is unleashed erratically. All the houses on one side of the block may be demolished while those across the street may remain untouched. They have occurred in many places around the globe, but the central and south-

* *A Planet Called Earth* (New York: Bantam Books, 1965).

western parts of the United States are particularly prone to tornadoes. Every year, 500 or 600 of them ravage the land, beginning in March in the Gulf states and moving north with summer. With little or absolutely no warning, they usually happen soon after the hottest part of the day.

Tornadoes are akin to hurricanes but do not rely on the heat of the sea surface for energy. In fact, meteorologists do not understand the source of their unparalleled violence. They happen in a clash between moist Gulf air and cold fronts from Canada. At first the warm sea air rises and moves counterclockwise to the north and east. It begins to whirl from the top, for reasons not well understood. Partly, it seems, because it has met the cold, clockwise moving air from the north. Why tornadoes form is a matter of conjecture and their suddenness makes control seem impractical. At present all the Weather Bureau can do in likely areas is predict "severe local storms."

Similar to tornadoes, but much less violent, are the waterspouts that occur at sea. The reasons for waterspouts are no better understood than those for tornadoes, but perhaps the difference in strength lies in the fact that the contrast in temperature of air masses that meet over the sea is not likely to be extreme. Ship captains try to avoid passing through them. Sailors must be weather-wise, even though they do not understand all the details of why it occurs.

It should be clear by now, hopefully, that no one understands why it all happens; but, in rebuttal to Mark Twain, the scientists are trying to do something about the weather. But the questions that can be asked about the weather are almost as infinite as the varieties of weather itself. No sure explanation exists for the jet streams, the 200 mile-an-hour and more winds, that circle the earth five and six miles above the surface. It is not known how

much rain actually falls on the earth each year or how much heat is absorbed from the sun. Until these facts are ascertained, statistical forecasting will always be handicapped. No one actually understands how evaporation works, how the water molecules defy the laws of gravity to get into the air, yet evaporation, part of the water cycle, is absolutely vital to man's existence on earth. There are several different theories on what makes rain fall. The causes in the tropics may be different from what they are in temperate zones. The desert areas of the world today were all, at other times, fertile lands. What happened to create the Sahara and the deserts of the American West? Why are some summers so dry and some winters so cold? What is the world's weather history?

What has been the past and what will be the future of the frozen Arctic and Antarctic? The answer to this last question is important to many more people than just scientists. It concerns everyone in the world who lives less than 300 feet above sea level.

XII.

The Biggest Laboratory in the World

THE Beardmore Glacier lies in the Transantarctic Mountains about 325 miles from the South Pole. The area, while not the most forbidding in the world, does not presently sustain much life. Nevertheless, Dr. Peter Barrett and fellow geologists from the Ohio State University chose to spend three months at its head during the 1967–1968 season of the U.S. Antarctic Research Program. This was during the southern summer when the temperature was fairly moderate, ranging from 20 degrees below zero to 20 degrees above. The scientists were guests of the National Science Foundation. The U.S. Navy flew them to their destination, and once there they set up tents, living, according to Dr. Barrett, fairly comfortably.*

Fossils were the lure that brought the men to this bleak place. Specimens of coal and plant fossils had been found in the Antarctic but no evidence that animals ever existed there, except for the birds and seals who kept very close to the coastal waters. The rocks around the Beardmore Glacier seemed promising because they were sedimentary

* Dr. Barrett, who grew up on a farm in New Zealand, does not have soft city standards.

and the remains of once living creatures might be deposited in them.

One day Dr. Barrett chose an ancient stream bed for investigation. Scratching through some undistinguished pebbles he came across something that seemed extremely interesting. He called his associate, David Johnston, over, who agreed that the object was undoubtedly a piece of bone. Before trying to move it, they waited until the sun got in the right position to make a photograph. The men wanted a record just in case the bone was damaged or destroyed while taking it out. Then Dr. Barrett went to work with a chisel. The fossil was so deeply embedded that it took three-quarters of an hour to remove it.

The find elated the scientists from Ohio State. The significance of the bone is that it was the first animal fossil ever discovered in the Antarctic. Subsequent study by an expert at the American Museum of Natural History showed that it was part of the jawbone of a labyrinthodont, a remarkable piece of detective work since it was only two inches long. Labyrinthodonts, whose fossils have also been found in South America and South Africa, were fresh-water amphibians who lived about 200 or 220 million years ago. Being fresh-water creatures, the labyrinthodonts would never have swum across the thousands of miles of salt water that now separate the Antarctic from South America and Africa. The animal's existence near the Beardmore Glacier adds strong support to the idea of Gondwanaland, the theory that all the southern continents were once part of the same land mass.

This group of geologists from Ohio State is only one of many hundreds of research parties that have been coming to the Antarctic ever since the International Geophysical Year (IGY) of 1957–1958. This joint effort by the scientists of 66 nations, which produced many results, in-

cluding the launching of the first satellite, the Russian Sputnik, and the discovery of the Van Allen radiation belt, seemed so rewarding to the U.S. government that it established year-round bases in the southernmost continent and American personnel have been there ever since. The U.S.S.R., Great Britain, Argentina, and New Zealand have all maintained active study programs on the continent since the IGY, and other nations send expeditions from time to time.

This interest in the frozen ends of the world is not new to explorers and scientists, but it has certainly accelerated over the years. For most of the nineteenth century and into the twentieth there has been activity at both ends of the world, but the North Pole seemed to capture more imaginations than the remote South Pole. Many attempts to reach the North Pole were made before Admiral Peary and Matthew Henson with four Eskimos accomplished the very difficult task in 1909. Peary's object was not so much scientific as simply to do something no one else had ever done before. The North Pole remained unvisited after Peary until Richard E. Byrd and Floyd Bennett flew over it in 1926. A few days later it was also crossed by a dirigible. In 1958 the U.S. nuclear submarine *Nautilus* crossed the North Pole under the Arctic ice. Today it is quite frequently approached by commercial aircraft and routinely covered by military planes of the United States, Canada, and the U.S.S.R.

The South Pole first yielded to Roald Amundsen, a Norwegian explorer, who reached it with a party of four men on December 14, 1911. An English naval officer and explorer, Robert Scott, was racing Amundsen for the honor of being first at the South Pole, but he and his group arrived one month too late. Scott and his group all perished on their return trip. The South Pole was not

seen again until Admiral Byrd, with pilot Bernt Balchen and a crew of two other men flew over it in 1929.

Polar exploration began with the search for the Northwest Passage, for a way to get around the impediment of the American continent and sail on to the rich trading ports of China. The names of some of the early men who ventured into areas near the North Pole are recorded today in a number of prominent geographical features such as Davis Strait, the Barents Sea, Hudson Bay, Baffin Land, the Bering Strait, Cook Inlet, Wrangel Island, and the Mackenzie River. The vast quantities of polar ice did not interest most of these men except for the fact that it represented danger.

Ice did not excite much scientific curiosity until the Swiss brought it to the world's attention. In a land full of glaciers, the Swiss were the first to become aware of the power of ice. They could see its work in the scour marks on mountainsides, in the moraines (hills of debris left behind by melting glaciers), and in boulders whose rock types did not conform with the rocks in position around them. Observant men reasoned that these boulders had been transported by glaciers from other locations. In 1821 a Swiss engineer named Vevetz read a paper before a local learned society in which he stated that all this rock evidence showed that the glaciers must have once been much more extensive. In fact the glaciers must have covered most of Switzerland.

Another Swiss, Jean de Charpentier, read another paper on the same subject in 1834. Charpentier traveled with a friend named Louis Agassiz to the Rhone Valley in France to study the moraines there. Agassiz agreed that they must have been created by glaciers and then he went further. Agassiz decided that glaciers must have covered all of

Northern Europe, extended even to central Asia, and also covered the Alps at a time when they were not so high.

Agassiz traveled to England and Scotland with his theory of an Ice Age and there he saw the same kind of rock evidence that existed on the continent. Those in Great Britain who had given any notice to scour marks and boulders out of position explained the marks as being created by flood waves and the boulders as being carried either by floods or by icebergs. Agassiz made many converts in British scholarly circles.

In 1846 he was invited to teach at Harvard University. Agassiz and later his son, Alexander, had a tremendous impact on science in the United States. (The complex of scientific institutions at Woods Hole on Cape Cod stems directly from a summer home Louis Agassiz had there and in which he did research work.) Naturally Agassiz looked for evidence of glaciation in North America and found it in abundance. Today children can show you the marks laid down by the glaciers all the way from Cape Cod and Long Island (formed by the debris from melting glaciers), past the Great Lakes scooped out by the ice, past the lakes of Wisconsin and Minnesota left behind by the retreating ice, all the way to Yosemite Valley, also scooped out by the ice which may have been as much as a mile high.

In Agassiz's day it was not all quite so obvious; but, it is said, by 1899 opposition to his idea by scholars had all but died out.* Agassiz thought he could see the remains of four distinct advances and retreats of the ice. He estimated that the events took place over a period of about

* Pockets of resistance remained, however. In 1905, Sir Henry Haworth in England published a 1,500 page argument against the whole idea.

one million years during the era known as the Pleistocence.

Research on the Ice Ages did not end with Agassiz's work. (There is today even an informal club of geologists who call themselves the Friends of the Pleistocene.) A few rather startling ideas have been suggested, and many questions remain unanswered. One remarkable thought is that before the glaciations there was no Mississippi River, that the Missouri River flowed into Hudson Bay, and that the Ohio went straight to the Gulf from a position much farther to the east than its present mouth at Cairo, Illinois. Some of the big questions about the Ice Ages are of considerable importance to the human race. The present state of the world's temperature and the existing sea level, which we take for granted, may not be permanent features at all. The last ice is considered to have receded only 11,000 years ago. Perhaps it will come back again.

One of the problems of the Ice Ages now is dating them. In 1956 Dr. Cesare Emiliani, then of the University of Chicago but now at the University of Miami, stated that, by dating the oxygen 18 content of fossil shells, he had proved that the glaciations lasted only 300,000 years, not a million. Two Lamont-Doherty researchers, however, D. B. Ericson and Goesta Wollin, published a paper in *Science* in 1968 which showed, by their dating techniques, that the Ice Ages of the Pleistocene lasted not just one million but two million years. Furthermore, there were eight ice invasions, not just four.

The length of the Pleistocene bears significantly on questions of evolution. Anthropologists generally agree that hominoids, the fashionable word today for man-type creatures, appeared at the same time as the glaciers that invaded Northern Europe and North America. Dr. Leakey, the celebrated researcher who has been finding

hominoid remains in the Olduvai Gorge of Central Africa, believes he has one skull at least one million years old. Did modern man evolve from quite different types in just 300,000 years or did it take two million? Why, it might be asked, did man evolve so rapidly in what must have been quite discouraging times? Was it in response to the challenge of the ice? It has been said, without much evidence, that instability of climate increases the rate of evolution. This may indeed be true, even if it cannot quite be proved.

What caused the Ice Ages? A few years ago Maurice Ewing and William L. Donn of Lamont-Doherty published a paper on the subject that caused some controversy. Their thought was that the North Pole, after being in a number of positions in the past, about one million years ago reached its present position. The Arctic Ocean at that time was not covered with ice. Winds could pick up its moisture, then drop it as snow over North America, Europe, and Asia. So much snow fell that it could not all melt in summer and each winter it piled higher, gradually turning into ice. The heavy ice would gradually spread out until it reached the limits that can be observed today.

This enormous mass of snow and ice would take up so much water that it would reduce the sea level. How much, no one knows for certain, but a reduction of 200 to 300 feet is generally accepted. With this much drop in sea level, the Gulf Stream which had been entering the Arctic from the Atlantic over a sill, keeping the Arctic from freezing, would no longer be able to reach that ocean. The Arctic would begin to freeze over and the winds could not pick up its moisture to make snow. With no replenishment from the north, the glaciers would begin to melt in the summer. Eventually the sea level would rise

to the point where the Gulf Stream could re-enter the Arctic Ocean and the whole cycle could begin again.*

The Ewing-Donn theory on the cause of Ice Ages is just one of a number that have been proposed. The classic theory explains glaciations by changes in the earth's orbit and in the axis of its rotation. Some new evidence gives weight to this theory; and, in a recent suggestion, we may be due for another Ice Age in the northern hemisphere about 80,000 years from now. When a considerable tilt exists, in the face the earth presents to the sun, the winters are cold and the summers hot. When less tilt exists, the contrast decreases and winters become warmer and summers cooler. During a cool summer, all the past winter's snow may not melt and conditions are right for building a huge ice sheet. Some theorists add that this can only happen when mountains are high and can act as a gathering point for the snow. We live in an era of high mountains, and mountain building may still be going on.

The changes in the earth's orbit and axis have been calculated by the laws of celestial mechanics for events in the past. The times when the summers were cold, because of changes in the earth's motion, seem to agree very well with the dates for Ice Ages. Recent chronologies made by the dating of radioactive thorium and protactinium, a rather rare element, have worked out the history of the climate for the past 250,000 years. The correlation between the changes which give the earth less sun and the times of glaciation are evidently quite close.

* To contradict all this, scientists in 1958 who had been taking sediment cores from the bottom of the Arctic Ocean while floating on ice island T-3, a U. S. project, reported that paleomagnetic studies of the samples showed that the Arctic "has not been warmer than at present for at least 1.5 million years and that there is no evidence of the Arctic Ocean having been free of ice in a similar period."

The classical theory never mentions the large sheets of ice that cover various parts of the world, but these sheets loom as threats now in the view of various other theorists. On February 20, 1969, *The New York Times* carried a story about the worries of Colonel Bernt Balchen, the pilot who flew Admiral Byrd over the South Pole. Balchen wrote a paper suggesting that the ice in the Arctic Ocean was thinning and that it would be an open sea within 10 or 20 years. If this should occur, tankers could reach the new Alaskan oil fields, but storm paths would also change, and the farmlands of North America and central Europe and Asia would become deserts. The rain that now falls on these areas would move farther north and, still farther north, heavy snows would fall to begin another period of glaciation.

Much evidence exists that, at least in the northern hemisphere, the earth has become warmer during the last century. The northern island of Spitzbergen has seen its average temperature increase by 13 degrees. The cold-loving birch trees, once common in the mid-Atlantic states, have gone back to Canada. Cod are fished in much more northern latitudes than previously. Some people estimate that the polar ice is only half as thick as it was during the 1890s when Fridtjof Nansen drifted in it for three years in his ship, the *Fram*.

On the other hand, Soviet and U.S. scientists who have been watching the Arctic Ocean closely for a number of years believe that the warming trend has now reversed itself, at least temporarily. No lessening of the ice thickness was noticed during the seven transits of the Arctic Ocean by U.S. nuclear submarines since 1958. Pack ice has reappeared in the fishing grounds off Iceland. If the earth is cooling now it may be that the increased pollution, all the particles in the air created by man's activities, may

be sufficient to cut down the amount of the sun's rays that reach the earth.*

Of all the theories about the Ice Ages, the most dramatic involves the great sheet of ice that covers most of the Antarctic. This land, larger than Western Europe and the United States combined, has ice that in places is 13,000 feet thick. Between two and three percent of all the water in the world lies tied up in this formation. In 1964 a scientist in New Zealand proposed that once about every 70,000 years this ice becomes so massive that vast amounts of it tumble into the sea. Not just icebergs, but sheets of

* The human race is certainly changing the atmosphere all around the fuel-consuming world. In La Porte, Indiana, over the past 20 years the rainfall has annually averaged 11 inches higher than in the surrounding countryside. Investigation suggests that La Porte, being downwind from the Chicago-Gary-Hammond industrial area, is receiving the effects of their air pollutants which act as cloud seeders. In addition to automobile exhaust and the air pollution from factories, it now seems that the exhaust trails from jets have often created high-flying cirrus clouds. Eventually all this cluttering the atmosphere with filth could seriously decrease the amount of sunlight the earth receives and thus cool it off. Statistics over the last 50 years show that this may indeed be happening.

There is a contrary worry, however. Some scientists believe that so much heat is being released into the atmosphere by the burning of fossil fuels that our environment is heating up. At the same time so much carbon dioxide is entering the air that the oceans, which usually absorb it, may no longer be capable of taking enough of it. If this is so, the air could become too full of carbon dioxide. Should this happen, much of the sun's radiation which is presently bounced back into space would be trapped by the gaseous blanket and we would have what is called a "greenhouse effect." The earth would become hotter and hotter. No one has offered any suggestions on how to dissipate this carbon dioxide cloud but it does present an interesting problem, both technically and scientifically. Little research is being done, in fact, on any of the effects of worldwide pollution. No doubt a disaster will have to occur before serious steps are taken. Even then someone will surely compain that the necessary remedies will "hurt business."

almost continental size. Flowing north these white sheets would reflect back so much sunlight that the world temperature would drop some 10 degrees. Such a drop would cause ice sheets to form at both poles. Eventually the floating Antarctic ice would break up, more heat would be received from the sun, and the earth would be warm again.

To provide a mechanism by which the ice could move off the Antarctic continent, it was suggested that enormous pressure from above, plus the flow of heat from within the earth below, would melt the base of the glacier. When a hole was drilled to the bottom of 7,000 feet of ice at Byrd Station in the Antarctic, just such a slushy condition was found. Many scientists are at work trying to fix dates for the changes that have taken place in the Antarctic. Rock dating is made difficult by the scarcity of fossils. Dating the ice by radioactive means, and finding when the ice cover first began to grow, may be relatively easier. When the age of the greatest sheet of ice in the world is known, then the theory that it caused the Ice Ages can either be confirmed or denied.

Interest in the idea of a huge southern continent began with the observation that the world did not seem balanced. Too much land existed north of the equator and a yet unseen counterweight ought to lie somewhere south of the imaginary line around the middle of the planet. Captain Cook, the first European on record to look for this theoretical continent, sailed south of the Antarctic Circle in 1775 but did not sight land. Somewhat later a Russian, Admiral Bellinghausen, found the sea that bears his name, and in 1820 an American, Captain Nathaniel Palmer, discovered the Palmer Peninsula, though he did not realize it was part of a continent. In 1823 James Weddell, an Englishman, sailed upon the Weddell Sea. An American, Charles Wilkes, sailed along the coast for 1,500 miles and

became the first man to announce that this land was continental in size. The British had an expedition in the area from 1839 to 1843 led by Sir James Clark Ross and consisting of two ships, the *Erebus* and the *Terror*. Ross's name is now applied to a sea and an ice shelf and Mount Erebus is the active volcano near the permanent U.S. McMurdo Station. After Ross, the Antarctic was more or less ignored until the turn of the century when the world began to read of explorers such as de Gerlache, Charcot, Amundsen, Captain Scott, Ernest Shackleton, and later Wilkins, Byrd, and Ellsworth.

Extensive activity in the Antarctic by men from the United States began with the first Byrd expedition in 1929. Byrd led a second expedition in 1933–1935 that explored 450,000 square miles of virgin territory. On his third trip Byrd charted most of the coast between the Ross Sea and the Palmer Peninsula, the land closest to South America. (In 1937 a British group had shown that the Palmer Peninsula was part of the Antarctic.) In 1946–1947 Byrd led still another expedition, sponsored by the U.S. Navy, that included 13 ships and 4,000 men. Additional exploring and mapping were done. In 1946 Commander Finn Ronne led another, private research expedition that found a considerable amount of previously unexplored territory. His wife and another woman were the first ever to winter over on the Antarctic. Admiral Byrd's last expedition was the Navy's Operation Deep Freeze, held partly to prepare for the massive effort of the International Geophysical Year. America's foremost polar explorer did not live to see the end of this expedition. The most spectacular feat of Deep Freeze undoubtedly was the establishment of a permanent base at the South Pole itself. When airplanes landed there in October, 1956, the men who stepped forth were the first to set foot there since

1912. Eighteen men lived at the Pole for the six dark months of the winter season. The programs of the IGY, which began in May, 1957, though mainly scientific, did include more exploring of the great continent. Exploration by U.S. personnel and groups from other nations continued until it could be announced, in April, 1968, that "U.S. Expedition Completes Exploration of Antarctica." A nine-man party, traveling on Sno-cats, crossed the last major unknown expanse on the continent, a portion of Queen Maud Land. Details remain to be filled in but all the important features of the Antarctic have now been seen by man.

Scientifically, however, the Antarctic may still hold the answers to many scientific puzzles. Before the IGY got underway in 1957 an international conference called it "... a region of almost unparalleled interest to the fields of geophysics and geography alike. In geophysics, Antarctica has many significant, unexplored aspects; for example, the influence of this huge ice mass on global weather; the influence of the ice mass on atmospheric and oceanographic dynamics; the nature and extent of aurora australis, for, although the aurora borealis has received considerable attention in recent years, the detailed characteristics of Antarctic aurora remain largely unknown; the possibility of conducting original ionospheric experiments northward from the South Polar Plateau during the long total-night season to determine the physical characteristics of the ionosphere during the prolonged absence of sunlight."

A more specific question of the time was whether the Antarctic was really a continent, one single land mass, or was it divided in two or could it possibly be a group of islands. Much seismic work through the thick ice seemed to indicate that it was one single body of land.

Geologically, however, the western and eastern parts of the Antarctic differ considerably in their makeup, the type of rocks with which they are built. The area of the Ellsworth, Horlick, Pensacola, and Transantarctic mountains seems much newer than the rest of the land. Part of the continent matches the rocks of South America while the other part compares closely with those of South Africa. Due to the action of sea-floor spreading these two parts may have broken off separately from their parent continents and drifted until they collided in what is now the land around the South Pole.

Many questions arose about the enormous Ross Ice Shelf. What caused it to form? Did the gulf on which it lies freeze over, then gradually reach it present height as thousands of years of snow piled up on it? Or is the shelf a glacier from land that has gradually extended itself? Does the shelf grow from water freezing at its base or is it constantly being eroded by the ocean currents below?

A very practical problem was whether the ice in the Antarctic is increasing or decreasing. A major loss of water from the great glaciers into the ocean could have drastic effects on all the seaports in the world. Observations at some points seemed to show reduced amounts of ice but these changes may have been due to purely local conditions. Scientists in the Russian, the Australian, and the French expeditions all concluded finally that the amount of ice in the Antarctic was becoming greater, even though the region is almost a desert with a very slight amount of snow falling each year.

Many expeditions conducted searches for minerals. The known extent of the coal beds was increased and small amounts of various metal ores were found, but in such inaccessible places that the continent seems safe from any commercial exploitation.

Biological studies did not figure in the concept of the IGY but penguins, particularly, proved too interesting to ignore. One American wondered how penguin eggs could be hatched in such deadly cold. Stealing one of the two eggs that a penguin lays, he inserted a telemetering device in it that would relay the temperature, then returned the rigged egg to the animal. The parent bird kept the egg quite close to its body heat as it sat on it for weeks at a time. In due course, the undisturbed egg hatched.

The Russians decided to take a census of an Emperor penguin rookery near their base. They thought they would do this from aerial photographs but the plane panicked the normally fearless birds who ran, leaving behind a nursery full of broken eggs. The Russians gave up picture-taking by this method.

One significant result of the IGY was a treaty, signed by all the countries that had claims to the continent, renouncing any territorial rights to the land and pledging to keep the Antarctic forever international and peaceful. The good feeling and spirit of cooperation that had developed between scientists of many nations during this project are what made the unusual treaty possible.

As noted, the United States has maintained research projects in the Antarctic continuously ever since the end of the IGY. Physical support for the scientific work has been the responsibility of the U.S. Navy. Like other government agencies, the Navy cannot resist the urge to build, and the largest base, at McMurdo Sound, has grown into a small town, complete with its own nuclear power plant. On the slightly more temperate Palmer Peninsula, even a three-story building has been constructed. Oceanographic research in the waters around the continent has been conducted for a number of years by the *Eltanin,* a ship owned by the National Science Foundation. In 1968

another vessel joined the Antarctic fleet. Named the *Hero,* for the ship in which Nathaniel Palmer first sighted the continent, and constructed entirely of wood, which will give under ice pressure instead of fracturing as steel does, the *Hero* will spend the six months of summer in biological studies.

Research in the Antarctic goes on in many different sciences, even to medicine which seeks to understand why wounds become infected so readily there and why any kind of cut is so slow to heal. Studies are also going on about the nature of sleep, in man and in seals. "Does adaptation to the marine way of life change the basic patterns of mammalian sleep?"

Biology in the Antarctic, as elsewhere, is largely a matter of description. Specifically, however, the land and the water around it present some special questions. How do the penguins use the sun to navigate? How do the Weddell seals, which are air-breathing mammals, manage to dive to 2,000 feet and return rapidly to the surface without getting the diving disease known as the "bends"? How do fish which lack red blood cells adapt to polar life? The Antarctic waters are rich in animal life because its waters are loaded with nutrient salts and the low temperature makes it possible for the water to hold more dissolved oxygen and carbon dioxide than warmer waters. This water, particularly in the world-circling current known as the Antarctic Convergence, is so rich in plant plankton and little creatures such as the shrimp-like krill, that it is often referred to as "soup." *

Geology, obviously, plays a prominent part in Antarctic study. The large amount of evidence of a once-tropical

* Antarctica has the widest diversity of marine life found anywhere. Many new species have been found during research in its waters.

climate there is one of the major supports of the continental drift theory. Comparing its rocks with those of other southern continents may also support the drift idea. Another problem is the widely differing kinds of rocks found in various parts of the land.

Students of the science known as glaciology obviously have no better place to work than on the greatest ice cap in the world. Besides wanting to learn whether the ice is melting or growing, or if there is any possibility of a massive ice slide into the sea, glaciologists want to determine when the ice began to form and why. Now that a hole has been drilled all the way through the ice, at a location where it was more than 7,000 feet thick, the ice can be melted at any depth and the water dated by a new, very sensitive radiocarbon dating technique developed by the Swiss. Meanwhile, a deep-sea sediment core taken on the *Eltanin,* material that had obviously been deposited by glacial action, was dated by electron microscope as belonging to the Eocene period (about 60 million years ago). Glaciation this long ago does not quite square with the 20-million-year age given for the warm-loving labyrinthodont.

Oceanographers have vigorously pursued their many different kinds of studies in Antarctic waters ever since the *Eltanin* was assigned to that exclusive duty. Then, in 1968, the Coast Guard made available its most powerful icebreaker, the *Glacier,* for penetration of the Weddell Sea, an icebound region where few ships had ever traveled before. In company with the Argentine icebreaker, *General San Martin,* the *Glacier* took advantage of a comparatively ice-free period reported by a weather satellite and entered the unknown area to make biological surveys and to lay newly developed Norwegian bottom buoys to measure the currents and the formation of bot-

tom water. It is believed that this extremely cold, highly oxygenated water from the Weddell Sea flows up the floor of the Atlantic as far as the latitude of New York City.* No one knows how it may affect events so far from its breeding place.

In the Antarctic, terrestrial physicists operate listening posts as part of the U. S. global earthquake monitoring network. They also observe the orbits of various satellites which may change in response to variations in the earth's gravitational pull. This can aid in making a more precise determination of the shape of the earth. (No scientist today believes that the earth's shape is simply that of a perfectly circular sphere.) The terrestrial physicists also hope to locate the south magnetic pole. The difficulty is that it may spread out over many miles or perhaps a number of south magnetic poles exist.

Also of concern in the area is "Upper atmosphere physics, the study of interactions among the Earth's air envelope, the geomagnetic field and incoming radiation from the sun and space. In the Antarctic it includes observations of such phenomena as aurora and airglow, whistler, hiss and other very low frequency radio noises, radio wave propogation ionospheric absorption, geomagnetic fluctuations, and cosmic-ray bombardment." The South Pole is important to studies of these matters because it is stationary relative to other points on the rotating globe. It offers the chance to have a continuous look at the same point on the earth. Although some understanding exists about a good deal in upper atmosphere physics, the exact way very low-frequency emissions are produced,

* An unusual feature discovered about Weddell Sea water is that it does not freeze at temperatures well below the expected freezing point for its salinity and temperature. This phenomenon is not fully understood.

and the source of their energy, are completely unknown although many ideas have been advanced.

Certainly no broad research program has ever been as long-term or as intensive as this one which 12 different nations are now conducting in cooperation in the Antarctic. Personnel from one country's station frequently spend months in friendly exchange visits to another country's station. Perhaps the exchanges have worked so well because the men, as scientists, have somewhat loftier interests than nationalism.

XIII.

The Detective Story Called Life

IF all the teeming life on our planet emerged from microscopically small beginnings, then the only witnesses can have been extra-terrestrial beings. If they were there, unfortunately they made no record of the events, and so scientific men have had to look for the story of life's origins in the debris living things left behind. Assuming that the first biological specimens on earth had no shells or bones, that they were soft and probably infinitesimal in size, it hardly surprises researchers that their traces have practically vanished during stretches of time that defy our senses.

Fairly abundant relics of marine life suddenly appear in rocks that have been dated as about 500 million years old. This era was first studied by Adam Segwick in 1835, who named it the Cambrian period, after a locale in North Wales were he worked. No traces of the previous four billion years seemed to exist, although, at the beginning of the Cambrian, the fossils included such highly organized creatures as the trilobites (whose relatives, the horseshoe crabs, have changed very little since that time). If the idea of evolution is correct, then creatures as com-

plex as trilobites must have developed from much simpler forms.

Thus the search for fossils older than the Cambrian has continued. In 1966 researchers from Harvard announced the discovery of fossil bacteria about two billion years old in samples from Ontario and Australia. These could only be seen through the electron microscope. In the same year they announced another fossil from South Africa said to be three billion years old. Then a scientist from the Scripps Institution announced a fossil, also from South Africa, that he dated as 3.5 billion years old. At about the same time other researchers reported on the remains of a jellyfish exposed in the rocks of the Delaware Water Gap which they considered to be three billion years of age.

Probably these Pre-Cambrian discoveries will stimulate more research on the subject and more fossil remains will be found, but it seems very unlikely that anyone will uncover the original living thing, if it *was* just a single thing. Many attempts to create life have been made in laboratories. Some minute components of life have been synthesized but nothing so far that grows and reproduces like our living cells. Attempts have been made to recreate the atmosphere supposed to exist on earth at the time of life's creation, but, though highly ingenious, none have yet been successful. The mystery of the origin of life remains in the hands of the theorists, for the moment. Rapid advances in the field of biochemistry may make that sentence obsolete at any time. (Or, perhaps, something unexpected found on the moon or one of the planets may prove to be the key to the riddle.)

In any case, very obviously, life exists here in every niche from the deepest part of the sea to the top of the highest mountain. In one form or another, life has conquered all of the surface of the earth. How has such total

victory been achieved? The partial answer, announced not much more than a hundred years ago, lies in the ability of living things to change over the generations, to adapt themselves to new conditions. The phrase "survival of the fittest" describes this phenomenon. For various reasons living things "mutate" or change during the process of generation. Most mutations are freakish and harmful, but some are beneficial and individuals whose mutations make them better suited to their environment are the ones more likely to survive.

Living things, of course, are also adaptable as individuals; this characteristic has been crucial in biology's conquest of the once inanimate earth. Birds, fish, and animals all migrate in search of food or away from unfavorable weather. Bears hibernate and trees grow dormant to live through the winter. Man travels everywhere on earth, and where the environment is inimical, he takes his suitable environment with him, for instance in submarines or pressurized airplanes.

In the course of adapting, both as individuals and as members of families capable of reproducing with one another, the varieties of life on earth have specialized almost beyond counting. Perhaps it all began with one single creature, neither plant nor animal, too small for our eyes to see. Then there were two, probably created by the simple process of dividing as the amoeba does today. Then, through the billions of years more and more different species developed, some successful, some incapable of adapting and thus candidates for extinction. At some time in the last million years a human-type creature appeared who was capable of speech. Undoubtedly some of the first words he used described the living things around him. Obviously these were important since he needed them for food. These first speakers began the classification of spe-

cies, living things sufficiently similar to one another so that male and female could unite and produce offspring with the same characteristics. Written descriptions of living things, and some mythical ones, began with the Greeks, and efforts to put life's variety on paper have continued ever since. A Swedish botanist who called himself Linnaeus first published in 1735 the binomial system of classifying plants and animals into their genus and species. Though much modified, the Linnaean system remains the basis of modern classification.

In the simplest definition, members of a common species are those who can breed with one another. This idea, however, does not satisfy a number of modern biologists. It may be possible, with assistance, to breed a hairless Mexican Chihuahua and an Alaskan huskie (although it is difficult to see how a Chihuahua female could bear any young of a male of such different size). A living animal might be produced. If, however, a resulting pup survived and had primarily Chihuahua characteristics, it would stand little chance of surviving in the Arctic. Are these two dogs the same species? They are both called dogs, but if interbreeding is the criteria, they are only barely the same species.

Some biologists grappling with the idea of species prefer to classify by structural similarities. Although this will work in many cases, in others there are such great differences between the sexes, or during various stages of development, that the true relationship becomes very difficult to recognize. Despairing of a rigid definition of species, some scientists have denied that any such thing really exists. However, mating is a fact of life and the inability to mate is another. Furthermore, anyone can see that a butterfly is not a whale. As a practical necessity, no better

word existing for the idea, biologists will continue to think in terms of species even if the term is inexact.

Species present another problem in that, even after at least two centuries of intensive study, no one can say how many different kinds exist. One can find in print statements such as that the number of species in the world is half a million and recognize such a figure as nothing more than a guess. In the case of fishes alone, estimates range between 15,000 and 40,000. Such disagreement reflects the fact that certain creatures change form so much during their life cycle that an individual captured at one stage of development does not look at all like what it would look like at another stage. Thus, the two stages acquire different names. (A young tadpole does not look much like a mature frog.)

In the matter of fishes, too, it seems certain that many species have never been observed by men. Obviously no one can tell how many kinds have eluded sighting or capture because of their agility, or because they live in such deep water, or because their habitat simply has not been investigated. The most famous such fish was the coelacanth, thought to have become extinct 60 million years ago, which fishermen suddenly found alive not many years ago in the waters off South Africa. New types of fish often turn up during oceanographic cruises devoted to biology. The creatures from the deep water, two and three miles down, are frequently quite bizarre. Species adapting to the extreme conditions at the bottom of the ocean have evolved into forms worthy of the best science-fiction imagination.

Past and present life in the sea pose innumerable questions. An assumption of paleontology has been that living shells will curve to the right in water of a certain temperature but curve to the left in water of another temperature.

Thus, the temperature of the water can be determined for the time when a fossil shell was growing. Is it safe to assume, however, that the ancient forms behaved in the same manner as their modern relatives on whom the observation was based? Who can say whether or not the response of shellfish to temperature might not have changed in the course of evolution?

One of the key questions in evolution is why any particular mutation benefited a particular species. One such query is why some sea creatures developed shells in the first place. The shell provides a certain amount of protection against enemies, but, in many cases, the shell immobilizes its owner. But other sea animals developed great speed or color camouflage or chemical means (like the ink-squirting octopus) to keep predators away. Why or how, in terms of evolution, were these particular methods chosen by the various species? What made one type of creature turn to shells while another chose an ink-like fluid, and still another developed spines like a sea urchin?

The extinction of species has worried scientists for generations. (The idea of magnetic reversals as the cause, with the increase of cosmic radiation and consequent damage to life during the change, is only the latest of many theories.) Dinosaurs, because of their size and because they had once flourished so successfully, are most often the subject of speculation. The question of extinction has produced many persuasive answers. One theory advanced blames changes in climate. A somewhat lowered temperature would reduce the amount of food available to plant-eating dinosaurs. Some might starve, leaving fewer prey for their carnivorous relatives. In the fight for survival, the carnivores might hunt the herbivores with such desperation that they were wiped out. The mammals of the time were so small that they could not provide sufficient

food for enormous creatures such as Tyrannosaurus rex. And so the carnivores went.

Another theory is based on the existence of dinosaurs not much larger than dogs. These lived by eating the eggs laid by large dinosaurs. If birds of this period and small mammals also hunted dinosaur eggs, as seems perfectly possible, such a developing species of egg eaters could have spelled doom to the dinosaur race.

Studies on reptiles in recent years have shown that, while they can tolerate a considerable decrease in temperature, a slight increase beyond their norm causes their blood temperature to increase rapidly. Reptiles have no inner cooling system and so, if the habitat changes from a swampy forest to some drier condition, they would find no water to cool off and thus die from the heat. Large masses of dinosaur bones found at certain places suggests that this may have happened.

"Racial senility" has also been mentioned as the cause for extinction. These animals dominated the earth for 100 million years, long enough, in some writers' opinions, for decadence to set in. "Racial senility," a difficult concept to understand, would make it impossible for the group to reproduce as rapidly as its numbers died out. This idea has also been expressed as the "exhaustion of living power." The cells become "diluted" and the old stock gradually grows "tired of division." No one has demonstrated, however, that this actually occurs in cells. The principle of life is vitality.

None of these explanations really seem to solve the puzzle. Changes in the conditions of life would affect other forms of life just as much as they would the dinosaurs. But all the other forms of life continued and only the apparently unadaptable dinosaurs spectacularly and mysteriously vanished, leaving nothing but bones behind.

Of course some reptile relatives still exist in the world today, but they provide no answer to the problem of the great catastrophe.

At the same time that dinosaurs began to disappear as the dominant race, about 60 million years ago, certain land mammals began to return to the sea. No one knows the conditions which caused animals who must breathe air to take up life in an environment which must, at least as far as the need for oxygen is concerned, have been a difficult one. Attempts to visualize conditions in which mammals would go back to live in the ocean have not seemed very convincing, but the whales and porpoises, mammals in the sea today, had ancestors once adjusted to the land. The earliest marine fossil ancestors of the whales and porpoises were called Archeceti.* Their bones have been found in the remains of the Eocene era. Other modern sea mammals, manatees, seals, and otters, are not closely related to the family of whales and porpoises and probably entered the sea at later dates.

Throughout recorded history, it seems that humans have held porpoises in high regard. Many folk tales and probably some true ones exist about porpoises who have helped swimmers in trouble. Watching a school of porpoises swim near the bow of a fast-moving ship, it seems impossible to believe they are not playing and having fun. If porpoises have never actually aided humans in the sea, neither has one ever attacked a human, although they are carnivorous. Today one can see porpoises close up at various marine shows and they have an expression on their faces which makes it seem as if they are smiling. They

* In *The Sea Around Us* Rachel Carson speculates that ancestors of whales were active predators who discovered the rich fishing in shallow waters and simply developed the habit of following their prey farther and farther out to sea.

have an expression most people find appealing. Lastly, researchers have learned that porpoises have large brains, may be quite as intelligent as humans, and certainly do talk with one another in their very social existence. No mystery exists about the fact that they do communicate with a large vocabulary and a considerable variety of sounds. The mystery lies in how they make the sounds, with their mouths usually closed, and none of the same equipment that man uses to talk. More importantly, how and when can the researchers learn to translate from the language of porpoises and establish meaningful communication? Dr. John C. Lilly, one of the most prominent researchers in the field of porpoise talk, has reported that some animals at his laboratory in the Virgin Islands have already mimicked the human voice. If only man could speak with porpoises how much he could learn about the sea. It does seem incredible that one could talk with another kind of animal. Porpoises' views on the nature of things and the purpose of life might be quite challenging to our conventional philosophies. Of course Dr. Doolittle talked with animals and had no trouble at all, but that was just fantasy (and his animals had very human-type minds). Considerable research is going on in porpoise speech and in training them to do tasks in the sea. Many of them are already adept at the stunts performed in aquarium shows. Achievement of true communication, an actual talk with a porpoise, would seem as great a marvel as any scientists are thinking of today.

Many other creatures in the sea as well as porpoises seem to make sounds by which they communicate. Numerous recordings have been made of whale talk. Their noises sound like the trumpeting of elephants. One report says that captive killer whales have even talked to each other from one city to another over the long distance line

using hydrophones at each end as the receiver and transmitter.

Drumfish and groupers make thumping sounds whose function may be to frighten away other fish. One species of fish is called the croaker because of the sound it makes. It resembles the noise produced by rapid blows on a hollow log. Toadfish produce a sound like a boat whistle that seems to have some relation to mating behavior. Sea lions, seals, puffers, crabs, snapping shrimp, and lobster are just a few among many noisy animals.

Much of the research about sound-producing animals is going on in the waters around Florida. One of the most common species there is the sea catfish which is particularly vocal at night, when it forms schools of thousands of individuals. These catfish emit a low grunt that may help orient it, like a sonar, in the crowd. Joseph D. Richard of the University of Miami has reported success in attracting certain kinds of commercial fish by artificial sounds in the water. The site of his work was the underwater acoustic and television facility of the Lerner Marine Laboratory off Bimini in the Bahamas. There Professor Richard made sounds that imitated those recorded before when carnivorous fish were feeding. These noises attracted groupers, mutton snappers, margates, and three varieties of sharks. He could observe his success by means of the underwater television camera. All the fish that responded were meat eaters. Herbivorous fish, plant eaters, ignored the sounds. This method of finding fish may very well be used soon for commercial purposes.

The various explanations given for fish making sounds are, at present, not much more than reasonable guesses. The numerous different colors of fish are explained as either defensive, to warn away predators, or of use in recognizing a mate of the same species. This does not explain,

however, why the fish who live around tropical coral reefs are so brightly colored while the fish that inhabit the colder waters nearer the poles are ordinarily drab and gray. Why, it has been asked, isn't it as important for fish to recognize each other in the North Sea as it is in the Caribbean?

Another question about fish color comes from the depths below 1,500 feet. There all fish are black, deep purple, or brown, with the exception of shrimps which come in gaudy shades of red, scarlet, or purple. Why did these colors evolve when, at such depth, the shrimp can only look black to fish who see them?

Among the curiosities about fish are the thousands of species that have the ability to make light. A common name for this is "phosphorescence," a name scientists do not like because no phosphorous is involved in the process. The proper term is "bioluminescence." Little heat is involved in its production, in contrast to the high heat of our light bulbs. Most of the animals in the sea that are bioluminescent belong to the lower orders. A few kinds of plants can also make light, as can some bacteria and the well-known firefly. For some reason yet unknown, no freshwater animals produce bioluminescence. More than half of all deep ocean fishes make light, even some kinds that are blind. Among the most spectacular possessors of bioluminescence are the numerous varieties of anglerfish. They carry a light that dangles in front of their mouths. Scientists have reached no general agreement on the function of bioluminescence in the animals of the sea. Perhaps it may attract a mate, or food, or frighten away an enemy, or aid in seeing a source of food. At various times it may have different uses. In some forms, such as bacteria, it may have no function at all.

Fish have many amazing characteristics for which no

sure explanation exists. Some, for instance, can survive in the deepest part of the ocean under the pressure of a thousand atmospheres. The pressure is equalized within and without, but such great pressure also produces chemical reactions that resemble congealing. No one knows why this reaction does not occur in the greatest depths.

Fish also navigate in schools. No leaders seem to exist and all the fish in a school are almost identical in size. They begin schooling when they are little fry, untended and abandoned by their parents. If isolated, they die, but no one knows why. Apparently they maneuver by eyesight, since fish that cannot see do not school. They also have a nerve system in their backbone which responds to some kind of external pressure. Schooling fish keep in exact formation, instantly correcting when getting too close or too far away. Who calls the turn when fish change course? What function does schooling itself serve? Many kinds of fish do not do it.

A number of species of sea animals navigate for long distances. Eels born in the Sargasso Sea return, as adults, to exactly the same fresh water rivers in Europe and North America where their parents lived until they swam out into the ocean to lay their eggs. Salmon, of course, always return to spawn in the river where they were born, even after an absence of two or three years. Sea turtles, similarly, come back to the beach where they were hatched in order to lay their eggs. Perhaps eels and turtles can recognize the special chemistry of their own river water but how do the turtles find the right beach? It is considered possible that turtles may reckon latitude by the height of the sun at noon, but figuring the longitude requires instruments.

Experiments in the Antarctic have shown that penguins use the sun in their navigation and apparently many other

birds do so as well. Some creatures seem to use the moon in their life cycle. The famous little grunion employs the lunar tides somehow to lay its eggs on the beaches of California. Something tells the grunion that shortly after the full moon during the months from March to August the tides will be at their highest. The male and female come in to the shore just after the flood stage has been reached. Between waves the female digs a hole in the sand, deposits her eggs, and the male fertilizes them. Then, on the next wave, they return to the sea. The eggs are not washed away because the tide has already begun to ebb. What mechanism gives the grunion such exquisite timing? (The grunion's special ability is just one example of a "biological clock." The world of life is full of them, examples being the swallows' return to Capistrano and, of course, the fertility cycle in the human female. Many of the clocks seem related to the sun or the moon but their location in living bodies does not show in books on anatomy.)

Even a brief study of life in the sea turns up so many wonders. A man trying to dive in the sea cannot go down very far nor return to the surface very abruptly, but marine mammals, with a quite similar breathing apparatus, can go very deep and then come up for air very quickly. Evidence shows that sperm whales sometimes hunt 3,000 feet down. Tuffy, a porpoise trained by the U.S. Navy, surfaced from 180 feet in 30 seconds with no ill effects at all. The Weddell seal, which has much the same ability, is now being studied intensively in hopes that something may be learned that will help man in his penetration of the sea.

Research into the biology of the sea is one of the most promising frontiers of science today. Knowledge about land plants and animals is many times greater because they are much more accessible and apparently more important to mankind. Now, however, it has become almost

a cliché to say that man must understand the two-thirds of the world that is ocean if he is to survive.

Sea research leads to such questions as how well can a fish see? Is its sense of smell better than its sight? More grimly, how do sharks spot their prey? They often seem to appear rapidly from considerable distances. Current research suggests that sharks can detect a commotion, such as a kicking swimmer or a torpedoed ship, at long range either by sound or some other vibration. Homing in, their sense of smell picks up the target. Close up, sharks rely on their vision, eying their target as they circle several times before dashing in for the kill. How strong is a shark's bite? Direct, controlled research on this has proved difficult; but the author has seen a strong steel Nansen bottle, used for water sampling, crushed by a shark's teeth. How long does it take for a shark to grow a new tooth? Seven or eight days. It has evolved this ability because, in its voraciousness, it loses many teeth. A shark may have as many as seven rows of teeth and it grows many thousands of them during a lifetime. Studies about creatures such as sharks may seem trivial or frivolous in a world burdened with very serious problems. On the average, only about 75 unprovoked shark attacks occur on humans all around the world in any particular year. Yet more and more people turn to the sea for recreation, and, with the increased use of diving gear, humans invade traditional shark territory with increasing frequency. Seventy-five known attacks per year is enough to generate a quite reasonable fear among swimmers. When in 1945 the U.S. cruiser *Indianapolis* was sunk by enemy action in the Philippine Sea, 880 lives were lost, a great but uncounted number of them from action by sharks. These animals quite reasonably generate a fierce hate among men; an understanding of them may show a way to control them by chemical or other means or

demonstrate a method by which they can be kept away from areas popular with swimmers and divers. Hemingway's *The Old Man and the Sea* showed what ravages they can create with a fisherman's catch. Commercial interests would welcome any way to modify shark behavior. A type of shark called the dogfish very seriously reduces the catch of fish in the waters off New England.

An intensely practical, rather new type of marine research comes under the heading of "drugs from the sea." The sea contains many kinds of animals highly toxic to man. Several species produce poisons known to be 200,000 times more powerful than the drugs now used in laboratories for the study of nerve and brain activity. Diluted, some of these toxins might be of great value in the control of tumor growth, in various blood coagulatory diseases, in the relief of pain, in the reversal of mental diseases, and in various digestive disorders. More than 300 kinds of toxicity are known in tropical fishes alone; but of all the dangerous fishes known, the active agents of less than a dozen have been worked out.

The sea also contains at least 1,000 different kinds of bacteria that might provide new antibiotics or other drugs useful in scores of different ailments. With the increasing resistance of many disease forms to penicillin and the various sulfas, new antibiotics are very desperately needed.

No one knows how the human beings in prehistory discovered the medicinal properties of various plants but, despite the mystery, they very obviously did. Until the historically recent development of synthetics such as aspirin, all ailments were treated with the products of nature, many of them the ridiculous concoctions of witchcraft, but others, such as the opium derivatives, highly effective. Most folk medicines derived from land plants, but a few came from the sea. The Chinese and the Indians

of South America long ago discovered that preparations of seaweed controlled goiter. South Sea islanders used seaweed for skin dressings, stomach disorders, and inflammations. Hawaiians made soup of marine algae for stomach disorders. Many other seaside residents used marine algae as vermifuges, medicines to get rid of internal parasites and worms. In modern Japan the poison of the puffer fish is used as a pain reliever and in the treatment of certain tumors. Researchers in this field of drugs from the sea believe they may one day produce cures for cancer, virus diseases, and heart ailments; not immediately, of course, but the sea obviously does provide a whole new realm of material to help cure the many ailments man is heir to. Like every advance in scientific thinking, this new medical advance to the sea raises hundreds, thousands, of new questions demanding answers.

A very urgent problem today concerns modern man's effect on the sea. It is not the realm of pure science to ask how technology, and its byproducts, are changing the ocean, but probably only science can give the answer. And science needs to know, particularly in the field of living things, if the scientist is not to wake up some day to the discovery that hardly any living things are left for him to study.

It seems preposterous to worry about the fact that man could eliminate life in the sea. In fact, so many people have cried "Wolf" about conservation that some serious people have become quite bored with the subject. The conservationists' view is a long one but, after Rachel Carson's *Silent Spring* predicted the disappearance of birds and this did not immediately happen, many citizens lost interest in the Cassandras. In the view of 50 years, however, or even much less, Miss Carson could turn out to have been much too prophetic. Considering man's enor-

mous destructive powers, no species on earth can be considered safe, least of all the human species itself. Beyond the classic extinctions (or near extinctions) of the passenger pigeon, the buffalo, the sperm whale, the sea otter, many other creatures have had their range severely limited and many species of animals in the United States are considered "endangered." Such once common creatures as bear, elk, moose, eagles, or wolves hardly exist except in protected situations. These sorry facts have been well-publicized and forgotten.

The new situation, not so well known, is that many nearby bodies of water may become, if not extinct, practically unusable. The Lake Erie problem, because so many million people live near it, work in factories along its shores, or farm not too distantly, has received a certain amount of recognition, but little action. Billions of gallons of industrial and human waste flow into it every year. Fertilizers and pesticides from farms flow into the lake in great quantities. Many freighters travel over it, leaving their own waste, and some people still go boating, although swimming is all but finished. Lake Erie is literally dying because of human activity. It is the largest body of water, so far, to which this has happened, probably because it has comparatively little outflow. Lake Michigan will be in as bad condition in a few years. It is surprising, and discouraging, how little effective outcry there has been against the probable loss of two great national resources. It may be that there are too many political jurisdictions involved and no one wants to spend money to right the matter, even if this is still possible. Scientific institutions, such as the University of Wisconsin nearby, are studying the problems of the Great Lakes (problems called oceanographic because of the lakes' size), but they have no power to do anything but explain to any interested

authorities what everyone already knows is happening.

The important, large estuaries of the United States, such as San Francisco and Chesapeake Bay, do not yet have quite the problems of the Great Lakes merely because ocean tides give them a daily, partial washing out. Organizations to "Save San Francisco Bay" and "Preserve the Environmental Integrity of Chesapeake Bay" exist and they have held many hearings and issued reports. The problem of accomplishing anything lies in the fact that so many people seek different goals.

In Chesapeake Bay, for instance, some people want to dig a deep water channel so that ocean ships can sail all the way up the James River to Richmond, Virginia. Oyster growers object, however, on the ground that this would destroy the seed beds on which three-quarters of their oysters grow. In this particular conflict, which involved many other interests as well, the state of Virginia enlisted all available scientists to determine the results of such a channel. They considered the problem from every conceivable aspect in hopes that a solution could be found that would be suitable to all parties involved. As part of the study, a very complete and expensive model of the whole river basin was constructed to show the interaction of tides, currents, river flow, and pollution under various conditions. The matter of the channel remains unresolved so far, but at least an attempt has been made to find the correct answers about man's effect on nature in an intelligent rather than an emotional, political manner.

Generally, men have given little consideration to the effect their activities have on the natural world around them and have apparently even cared less. The results often come as a surprise. The city fathers of San Francisco were shocked a few years ago to discover that indiscriminate landfills along the shores had reduced their bay to

half of its original size, with predictable dislocations in the fish and game life and a considerable increase in pollution. The accidental introduction of a "walking" Asian catfish and the water hyacinth have created very considerable upsets in the balance of nature in Florida waters. The California sardine is no longer a commercial fish, and men from New Bedford, who used to harpoon whales from rowboats, drove them off more than a hundred years ago. DDT is found in the flesh of animals in the Antarctic where the pesticide is never used. Why is this the only kind of pesticide found there, and by what means did it arrive? The interruption of Nile water by the Aswan Dam has cut the flow into the Mediterranean and severely changed the fisheries of the eastern part of that sea. Now people propose a sea level canal between the Caribbean and the Pacific through Central America with an intermingling of species that has explosive possibilities. The oil spillage into the sea from offshore wells, from tankers cleaning their tanks, and from tankers in accidents has increased, and no one has found a way to clean up the mess on beaches or reckoned the damage to birds and fish. Now, although the circulation of deep ocean currents is barely understood, it is proposed that vast amounts of radioactive wastes be dumped into the sea. Most of the pollutants in the world eventually reach the sea. At what point will the ocean become saturated? Even before then, when will we see our last Chesapeake oyster?

At present the sea acts both as a pasture and as a garbage can. By the nature of things, both uses cannot increase indefinitely. Marine biologists today try to throw some light on the dilemma by asking and answering the really hard questions. What is the actual fish population of the world today and how many could safely be harvested? This is obviously a very tough problem. The depths of the

sea are invisible and fish range all the way from the surface to the bottom. Some areas are very productive and some are almost deserts. Fish populations fluctuate widely. The sardine catch in the Indian Ocean was only 7,000 tons in 1956. The next year it was almost 200,000 tons. The catch of Norway herring plunged from over one million tons in 1956 to just 69,000 tons in 1961. Fish migrate, though the pattern for this is hardly understood. Presumably they respond to changes in light, temperature, salinity, and the availability of prey. Any one of these factors could change as, for an instance, in the Humboldt Current off South America. When its temperature changes during *El Niño* the mortality of fish is staggering. The mortality of fish during "red tides," when the plankton known as dinoflagellates bloom over miles of ocean surface, is also staggering. Fish lay millions of eggs and normally few mature but, under exceptional circumstances, perhaps many would mature and the population suddenly change considerably. One proposal for taking a fish census has been by sound, a system known as bio-acoustics, which might give some idea of population density, but could it distinguish between an edible cod and an inedible lantern fish? Tagging fish has also been done, but how do you tag a blue crab which sheds its shell? One can see why no accurate fish count exists at present. Someone may devise a good method, but it can certainly never approximate the human census of a city block.

Inquiry about the unknown in marine sciences produces a very rich harvest of problems. Why is the range of temperature in which tropical fish can survive so much less than the range possible for cold-water fish? What factors cause variations in geographically separated populations of the same species? Why do day and night fish populations differ near the surface? How can a rich variety of life exist

at mid-ocean levels, well below the sunlit layers and far above the bottom? What is the role of dissolved organic materials in the sea? How could geographic isolation and subsequent evolution occur in an open ocean? Little is known about fungi and yeasts in the ocean. (Almost anything that can be learned will be useful.) Does the level of pollution have a greater effect on adult species than upon the larval stages? What regulates the population of ocean species? What are the possibilities of herding and of farming in the sea?

To illustrate the degree to which knowledge is needed, one might quote Dr. John A. Knauss, Dean of the Graduate School of Oceanography of the University of Rhode Island. "If our estimate of the number of copepods (small crustaceans) of a given species one finds in a cubic meter of water is correct, then the chances of two copepods of the same species meeting by random movement suggests that such an event would happen for a given copepod about every two years. There must be something missing in our reasoning, but just at the moment it does seem highly unlikely that the species can maintain itself under the circumstances."

The mating of copepods or the drifting of continents differ vastly in scale, though both are equally mysterious. The solution to either problem would be fascinating and still leave an infinite number of problems for the next man who may be interested. However our earth and its life came to be, there is no lack of material to satisfy the human curiosity.

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